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MEDICAL RESEARCH PERFORMED ON THE FLIGHT PROGRAM OF THE SOYUZ-TYPE SPACECRAFT

L. I. Kakurin

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ABSTRACT: Preflight, inflight and postflight examinations and analyses of the physical condition of the crews of the "Soyuz" -type spacecraft indicated that the most serious problems enumerated were (1) rushing of blood to the head on insertion into orbit, (2) demineralization of bone tissue caused by weightlessness, (3) difficulty in readjusting to Earth's gravity (especially the "Soyuz-9" crew), (4) definite changes in the cardiovascular system, all of which were functions of flight duration. Experiments with plant seeds and animals (turtles) are also summarized.

The successful completion in the USSR of a series of manned spaceflights with the "Vostok" and "Voskhod" spacecraft laid the necessary foundations for carrying out the program of studies aboard the "Soyuz" craft. /4*

The flight of the "Soyuz" manned spacecraft took place during the period from 1968-1971. The principal tasks of the flights were the following: development of piloting systems, rendezvous of spacecraft launched at different times, approach and docking of spacecraft, making a single station out of two spacecraft in Earth orbit, crossing of two cosmonauts through outer space from one spacecraft into another, evaluation of the effectiveness of life-support systems and a study of physiological reactions during a long spaceflight.

The comprehensive data on manned flights are shown in Table 1.

The "Soyuz-1" spacecraft, piloted by cosmonaut V. M. Komarov was launched on 23 April 1967. The flight lasted more than 24 hours. The cosmonaut perished tragically while making a landing.

On 26 October 1968, the "Soyuz-3" spacecraft was launched into orbit; it was piloted by pilot-cosmonaut G. T. Beregovoy. During the flight, Beregovoy performed a number of maneuvers in space with the aid of an automatic system of manual control, including an approach to the unmanned "Soyuz-2" spacecraft.

*Numbers in the margin indicate pagination in the foreign text.

TABLE 1. GENERAL DATA ON THE FLIGHT OF THE SOYUZ SPACECRAFT.

Spacecraft	Cosmonauts: Name	Cosmonauts: Born	Date and time of launching	Initial Orbital: Apogee	Initial Orbital: Perigee
"Soyuz-3"	G. T. Beregovoy	1921	26 Oct. 1968, at 1134 hours	225	205
"Soyuz-4"	V. A. Shatalov; on the 36th orbit A. S. Yeliseyev, and Ye. V. Khrunov entered from the "Soyuz-5"[1]	1927 1934 1933	14 Jan. 1969 at 1039 hrs.	225	173
"Soyuz-5"	B. V. Volynov A. S. Yeliseyev Ye. V. Khrunov	1934 1934 1933	15 Jan. 1969 at 1014 hrs.	230	200
"Soyuz-6"	G. S. Shonin V. N, Kubasov	1935 1935	11 Oct. 1969, at 1410 hrs.	223	186
"Soyuz-7"	A. V. Filipchenko V. N. Volkov V. V. Gorbatko	1928 1935 1934	12 Oct. 1969, at 1345 hrs.	226	207
"Soyuz-8"	V. A. Shatalov A. S. Yeliseyev	1927 1934	13 Oct. 1969, at 1329 hrs.	223	205
"Soyuz-9"	A. G. Nikolayev V. I. Sevast'yanov	1929 1935	1 Apr. 1970, at 2200 hrs.	220	207

[1]A. S. Yeliseyev and Ye. V. Khrunov spent a total of 1 day, 23 hours and 39 minutes in flight aboard the "Soyuz-4" and the "Soyuz-5".

TABLE 1 (Continued)

Parameters / Period of revolution	No. of revolutions	Duration of flight	Values of Microclimate Parameters			
			P mm Hg	T°C	P O_2 mm Hg	P CO_2 mm Hg
88.6	64	3 days, 22 hrs, 51 min.	767-836	18.3-22.6	184.4-248.0	1.0-2.9
88.2	48	2 days, 23 hrs, 14 min.	750-800	18.0-22.0	157-186	0.1-8.4
88.7	49	3 days, 0 hours, 46 min.	767-840	16.0-21.6	168-238	0 -12.3
8.36	80	4 days, 22 hrs, 42 min.	720-848	16.5-23.5	168-252	6.5-15.1
88.6	80	4 days, 22 hrs, 41 min.	750-809	18.0-23.6	160-202	0.8-12.0
88.6	80	4 days, 22 hrs, 41 min.	735-825	18.3-23.6	186-240	1.1-15.0
88.6	286	17 days, 17 hrs, 0 min.	732-890	17.0-28.0	157-285	1.3-10.7

The latter had been launched into orbit as an artificial Earth satellite on 25 October 1968.

The flights of the "Soyuz-2" and "Soyuz-3" spacecraft were a necessary step in the continuing performance of complex experiments involving docking of spacecraft and transfer of cosmonauts from one craft to another. For this /6 purpose, the "Soyuz-4" spacecraft was launched on 14 January 1969, piloted by pilot-cosmonaut V. A. Shatalov. Then on 15 January 1969 the "Soyuz-5" spacecraft was launched into orbit; its crew included the following pilot-cosmonauts: the commander of the craft, B. V. Volynov, flight engineer A. S. Yeliseyev and engineer-investigator Ye. V. Khrunov. Approximately 24 hours after the "Soyuz--5" was launched, on 16 January 1969 at 1120, on the 34th orbit of the "Soyuz-4" or the 18th orbit of the "Soyuz-5," the craft performed rendezvous, approach and manual docking. Then on the 35th (19th) orbit, Yeliseyev and Khrunov emerged into deep space. The cosmonauts simultaneously spent about 1 hour under deep-space conditions and on the 36th (20th) orbit entered the orbital section of the "Soyuz-5" spacecraft. On 16 January 1969, at 1520 hours on the 37th (21st) orbit, the spacecraft were undocked and continued their flights separately. During the flight, the cosmonauts controlled the craft manually, maneuvering in space and repeatedly moving the craft to new orbits. After the flight program was completed, the "Soyuz-4" and "Soyuz-5" spacecraft landed at the appointed location on 17 January and 18 January 1969, respectively.

On 11-12 and 13 October 1969, the "Soyuz-6", "Soyuz-7" and "Soyuz-8" spacecraft were consecutively launched into orbit.

The craft were piloted by pilot-cosmonauts of the USSR: "Soyuz-6"--G. S. Shonin (commander), V. N. Kubasov (flight engineer), "Soyuz-7"--A. V. Filipchenko (commander), V. N. Volkov (flight engineer), V. V. Gorbatko (engineer--investigator), "Soyuz-8"--V. A. Shatalov (commander), A. S. Yeliseyev (flight engineer).

The outstanding feature of the flight of the "Soyuz-6", "Soyuz-7" and /7 "Soyuz-8" spacecraft was the numerous maneuvers which they executed in the course of changing orbits and approaching one another under manual control.

During the period from 1 to 19 June 1970, cosmonauts A. G. Nikolayev and V. I. Sevast'yanov performed an 18-day flight aboard the "Soyuz-9"--the longest of the "Soyuz" flights.

The principal tasks involving medical investigation on this flight involved further study of the phenomenonology of the changes involving various systems of the human organism in a state of weightlessness lasting up to 18 days, as well as the condition of its reserve capacity upon return to ordinary conditions of terrestrial existence.

The materials which the medical safety officials acquired following completion of the program of the flights of the "Vostok," "Voskhod," "Mercury," and "Gemini" spacecraft still did not provide complete information regarding the characteristics of changes in physiological parameters. Medical observations that had been obtained earlier had to be used with great care, since one of the physiological problems remained unsolved--are the human reactions produced primarily by the effect of weightlessness or does it involve a cumulative effect of weightlessness and hypokinesia? The critical role of these two factors remained unclear. The answer might be found if the crew members were provided an opportunity for active muscular activity without their spacesuits in the open sections of the spacecraft.

Slightly different conditions were expected from the standpoint of emotional stress, since it was primarily group activity of the crew members that was involved. The flights of the "Soyuz-6" to "Soyuz-8" spacecraft were /8 particularly valuable in this regard, when seven cosmonauts were in orbit around the Earth simultaneously.

From the medical standpoint, it was important to determine whether or not the changes in physiological functions become more severe as the length of the flight increases, whether or not the human organism is able to compensate for this and, finally, what reserves the organism may draw upon when subjected to this background of various stresses.

During the flights aboard the "Soyuz" spacecraft it was possible to evaluate the condition of 15 cosmonauts, some of whom were in space on two occasions, and the conditions of existence and professional activity of the majority of cosmonauts were the same (the difference lay primarily in the duration of the flight). The total time spent in space during the "Soyuz" program amounts to about 2,042 man hours.

The principal problems handled in the medical and biological studies during the flights of the "Soyuz" spacecraft were as follows:

--further study of the phenomenonology of the changes involving various systems in the human organism under conditions of prolonged (up to 18 days) weightlessness;

--study of the state of the reserves of the human organism upon return to ordinary conditions of terrestrial existence following a long stay in space;

--study of the dynamics of the working ability of the cosmonauts in carrying out appropriate work operations and on the basis of an evaluation of the performance of special tests.

CHAPTER I.

GENERAL CHARACTERISTICS OF FLIGHT CONDITIONS ABOARD THE "SOYUZ" SPACECRAFT

The flight of the "Soyuz" spacecraft took place during a quiet radiation situation. As we would expect, the maximum values of the integral dose of radiation were recorded during the 18-day flight of the "Soyuz-9" spacecraft. When the flight was over, this value was as follows: for A. G. Nikolayev, 237 and for V. I. Sevast'yanov, 408 mrad with an average dose rate of 13 and 22.6 mrad per day, respectively. Of course, these values posed no danger to cosmonauts Nikolayev and Sevast'yanov. /11

During the 3 to 5 day flights of the "Soyuz" spacecraft, the integral radiation doses were much lower and varied between 58 and 85 mrad with an average dose rate of 11.8-31.5 mrad/day (Table 2).

The life-support systems aboard the "Soyuz" spacecraft maintained the parameters of the microclimate in the crew quarters within the set limits, so that their variation had no important influence on the state of health and working ability of the cosmonauts. The maximum range of variation in the parameters of the microclimate was observed during the flight of the "Soyuz-9": the combined pressure was 732-890 mm Hg, the partial pressure of oxygen was 157-285 mm Hg, the partial pressure of carbon dioxide was 1.3-10.7 mm Hg, the level of the relative humidity was 40-75%, the temperature in the quarters was 17°-28°C (the temperature could be regulated by the cosmonauts themselves). During the flights of the other "Soyuz" spacecraft, the variations that took place in the microclimate parameters did not exceed the limits mentioned above (Table 1). During the crossing of cosmonauts Yeliseyev and Khrunov from the "Soyuz-5" to the "Soyuz-4", their personal life support systems maintained an absolute pressure in their suits which was between 241 and 268 mm Hg, with a partial pressure of carbon dioxide equal to 0.1-0.4 mm Hg and an air temperature at the outlet from the heat exchanger of 19.4°-19.8°C. /12

TABLE 2. INTEGRAL DOSES RECORDED DURING THE FLIGHTS OF THE "SOYUZ" SPACECRAFT

Spacecraft	Date of Launch	Crew	Duration of flight, days	Integral dose, mrad				Average level of dose, mrad per day
				Chest	Right side	Right hip	Average	
"Soyuz-3"	26 Oct. 68	G. T. Beregovoy	4	85	85	-	85	21.2
"Soyuz-4"	14 Jan. 69	V. A. Shatalov	3	60	54	63	59	20.0
"Soyuz-5"	15 Jan. 69	B. V. Volynov	3	75	67	-	71	23.6
		A. S. Yeliseyev	2	61	56	71	63	31.5
		Ye. V. Khrunov	2	65	48	70	61	30.5
"Soyuz-6"	11 Oct. 69	G. S. Shonin	5	64	66	87	72	14.4
		V. N. Kubasov	5	61	58	87	69	14.0
"Soyuz-7"	12 Oct. 69	A. V. Filipchenko	5	65	72	67	68	13.6
		V. N. Volkov	5	61	56	57	58	11.8
		V. V. Gorbatko	5	62	63	66	64	12.8
"Soyuz-8"	13 Oct. 69	V. A. Shatalov	5	80	61	77	73	14.2
"Soyuz-9"	1 June 70	A. G. Nikolayev	18	222	240	250	237	13.0
		V. I. Sevast'yanov	18	385	390	448	408	22.6

TABLE 3. AVERAGE DATA ON THE COMPOSITION AND CALORIC CONTENT OF THE FOOD RATION

Spacecraft	Cosmonauts	Daily caloric content of ration, kcal	Proteins in g	Fats in g	Carbohydrates in g
"Soyuz-3"	G. T. Beregovoy	2,635	143	106	254
"Soyuz-4, 5"	V. A. Shatalov B. V. Volynov A. S. Yeliseyev Ye. V. Khrunov	2,635	143	106	254
"Soyuz-6, 7, 8"	G. S. Shonin V. N. Kubasov A. V. Filipchenko V. N. Volkov V. V. Gorbatko V. A. Shatalov A. S. Yeliseyev	2,635	143	106	254
"Soyuz-9"	A. G. Nikolayev V. I. Sevast'yanov	2,800	139	88	354

The food ration for the crews of the "Soyuz-3"-"Soyuz-5" spacecraft were composed of a combination of food products in ready-to-use form, both dehydrated and preserved by other methods (sterilization, etc.). The weight of the average daily ration including packaging amounted to 800 grams with a volume of 1.4 liters. An analysis yielded the following composition: proteins-143 g, fats-106 g, carbohydrates-254 g, to make a total caloric content of 2,635 kcal (Table 3). The ration was made up in the form of a 3-day menu with food being eaten four times a day. During the flight, the dehydrated products were given a lower rating by the cosmonauts than the ones which were preserved by sterilization, so that after corrections had been made the food ration for the crews of the "Soyuz-6"-"Soyuz-8" spacecraft had the same food value as the preceding ones but contained less dehydrated products, since some of them were replaced by products that were preserved by other methods. This change was appreciated by the cosmonauts.

In the case of the "Soyuz-9" crew, in view of the length of the flight and the special active schedule of the cosmonauts, the average daily caloric content of the ration was increased to 2,800 kcal, the assortment of food products was considerably increased and provisions were made for heating the main courses and beverages (coffee, cocoa). The average weight of the daily ration for the "Soyuz-9" crew was about 1,460 g, which broke down as follows: water-853 g, proteins-139 g, fats-88 g, carbohydrates-345 g. The ration was balanced in terms of irreplaceable amino acids and contained normal amounts of the basic mineral elements and polyunsaturated fatty acids. In addition, the cosmonauts each took vitamin pills twice a day, with the following composition: A-3,300 /14
IU, B_1-2.58 mg, B_2-2 mg, B_6-3 mg, B_{12}-12 mg, C-75 mg, E-10 mg, nicotinamide-20 mg, foleic acid-0.5 mg, calcium pantothenate-3 mg, lutin-10 mg. Finally, it should be mentioned that the assortment of products was selected (as a rule) with consideration of the individual tastes of the cosmonauts and satisfied their requirements completely.

The average daily consumption of water by the members of the "Soyuz-9" crew was 1.95-2.15 liters per man (including the water that was contained in the food products and the beverages as well as metabolic water, 0.35 liters).

The supplies for personal hygiene to be used by the "Soyuz" crews included different types of napkins and towels, both dry and moistened with special lotion, intended for use on the skin of the face, palms of the hands, treating the gums, etc. The flight program of the "Soyuz-9" provided for special "bath" days (the 7th and 14th days of the flight), when the cosmonauts changed their underclothing and wiped their bodies with a towel moistened with lotion and then dried themselves with another towel. The equipment for personal hygiene aboard the "Soyuz-9" also included mechanical and safety razors, combs, etc.

The program of work and rest for the cosmonauts during the first flights aboard the "Soyuz" spacecraft were based on maintenance of a 24-hour daily cycle with 8 hours of sleep once a day. The maximum duration of a single watch did not exceed 5 hours. The crew ate four times a day, with approximately equal intervals between meals. After sleeping and before eating breakfast the /15 crew performed physical exercises.

The change in the work and rest schedule from one flight to the next involved lengthening the period of free time, increasing the amount and duration of the physical exercise, and also reducing the total amount of work hours (Table 4).

During the flight of the "Soyuz-9", the cosmonauts also slept for 8 hours. Twice a day, they carried out a special set of physical exercises which lasted 60 minutes each. The morning set of exercises began approximately 2 and 1/2 hours after awakening, while the evening exercises took place two hours before going to bed. The time allowed for eating was increased to 40 minutes and provision was made for heating the food before eating. Approximately 2 hours were allowed for resting after dinner. Hence, the evolution of the work and rest schedule led to a considerable improvement in the vital activity of the men aboard the spacecraft.

During the flight of the "Soyuz-9", in conjunction with the precision of the orbit, it was not possible to maintain a normal daily rhythm all during the flight. The beginning of the day was shifted stepwise, so that on the first

TABLE 4. SCHEDULE OF WORK AND REST OF THE COSMONAUTS DURING THE "SOYUZ" SPACEFLIGHT

Spacecraft	Cosmonauts	Sleep in hours	Physical exercise in min	Breakfast in min	Physical exercise in min	Second breakfast in min	Rest in min	Lunch in min	Rest in min	Physical exercise in min	Dinner in min	Watch in hrs*
"Soyuz-3"	G. T. Beregovoy	8	25	25	-	40	40	30	-	-	30	4
"Soyuz-4"	V. A. Shatalov	8	30	25	-	30	-	30	30	-	30	5
"Soyuz-5"	B. V. Volynov	8	30	25	-	30	-	30	30	-	30	5
	A. S. Yeliseyev	8	30	25	-	30	-	30	30	-	30	5
	Ye. V. Khrunov	8	30	25	-	30	-	30	30	-	30	5
"Soyuz-6"	G. S. Shonin	8	25	30	-	30	20	40	-	-	30	5
	V. N. Kubasov	8	25	30	-	30	20	40	-	-	30	5
"Soyuz-7"	A. V. Filipchenko	8	25	30	-	30	20	40	-	-	30	5
	V. V. Gorbatko	8	25	30	-	30	20	40	-	-	30	5
	V. N. Volkov	8	25	30	-	30	20	40	-	-	30	5
"Soyuz-8"	V. A. Shatalov	8	25	30	-	30	20	40	-	-	30	5
	A. S. Yeliseyev	8	25	30	-	30	20	40	-	-	30	5
"Soyuz-9"	L. I. Nikolayev	8	-	40	60	40	-	40	120	60	40	5
	V. I. Sevast'yanov	8	-	40	60	40	-	40	120	60	40	5

* The maximum duration of one watch per day is given.

day of the flight the cosmonauts went to sleep at 0700 hours Moscow time, and at the end of the flight they were going to bed at nearly midnight.

Aboard the "Soyuz-3"-"Soyuz-8", due to the short duration of the flight (up to 5 days), the motor activity of the cosmonauts was not regulated. The long duration of the "Soyuz-9" flight (18 days) made it necessary to organize /17 the motor activity of the cosmonauts with an eye toward preventing possible disturbances caused by a number of flight factors.

On the basis of the experimental material that had been collected in the course of solving a number of the partial problems of organizing the physical training of cosmonauts in flight, the principles of this training were revised and a method worked out for physical exercises that were suitable for the special conditions existing aboard the "Soyuz-9" spacecraft.

The program of physical training was based primarily on the general didactic and physiological principles of athletic training with some special aspects dictated by the conditions of spaceflight.

The physical training program was organized with a consideration of the cyclic nature of the stresses and the variations in the training cycle. The training process consisted of repetition four times a day of a cycle of physical exercises. During the first three days it was required to perform the standard program of exercises, increasing the load from the first day to the third.

The selection of the exercises in the program, the number of times they were repeated and the rate at which they were performed had to insure prolonged maintenance of the basic motor characteristics at a high level by planning the program for each day in terms of rate, force and endurance. The daily energy consumption of the physical exercises when performed twice (a total of 2 hours) varied between 250 and 400 kcal per day.

The fourth day of the training program was set aside for active rest. On this day, the stress was not planned and the cosmonauts were able to select the exercises and their amounts according to their preference.

The principal task for the fourth day of the cycle was rest and physio- /18 logical adjustment of the organism to the new schedule.

To accomplish these goals, the "Soyuz-9" was equipped with a number of devices which provided for the supporting function of the bodies of the cosmonauts and stresses on various parts of the body (a system for holding the body in a vertical position against a special support, expanders, loops, pulleys, etc.). The force of the restraining apparatus was about 30 kg. The supply of expanders was such that forces of 10-40 kg could be applied to the hands, legs, and trunk. The body was held against a support by elastic belts and a special suit, to ensure linearity of the forces from the lower to the upper points of shifting of the center of gravity of the body.

The program of exercises included cyclic exercises (running, walking, jumping, squatting), various isometric exercises, exercises designed for anti-gravitational musculature, the muscles of the hands, neck, etc. for purposes of coordination.

The set of exercises was memorized and mastered by the crew members long before the flight.

According to the cosmonauts' reports, they found their training comfortable and satisfying. All the exercises were performed according to the program. At the beginning, the exercises involving the isometrics caused unpleasant sensations in the head, but later these sensations caused no problems. After training, the cosmonauts felt encouragement, energy, and a lift to their spirits. Their subjective sensations were supported by objective data which indicated that the physiological reaction to a standard physical load (on the basis of a functional test) remained [Note: text missing], which indicated a retention [Note: text missing].

CHAPTER II.
MEDICAL MONITORING SYSTEM

To perform the physiological studies and medical monitoring of the condition of the crew members aboard the "Soyuz" spacecraft, a special method of obtaining medical information was devised on the basis of the experience obtained on previous spaceflights. /19

On the "Soyuz" flights, the following types and sources of information were used for operational medical monitoring of the state of health of the cosmonauts.

--results of an analysis of radio conversations between the crew and the ground stations;

--data from television observations of the cosmonauts;

--verbal responses of the cosmonauts regarding their sensations;

--analysis of the effectiveness of performance of the flight program as a whole and its individual elements by the crew members;

--an analysis of the parameters characterizing the state of the microclimate of the crew quarters aboard the craft;

--telemetric data on the basic physiological parameters.

The medical monitoring apparatus aboard the craft provided for measurement and transmission of the electrocardiogram (EKG), seismocardiogram (SKG), pneumogram (PG) and the frequency of cardiac contractions (CC) of each cosmonaut to ground stations in line-of-sight zones along a telemetry channel (Figure 1).

The medical information was collected by means of systems of physiological sensors that were attached to the bodies of the cosmonauts (Figure 2).

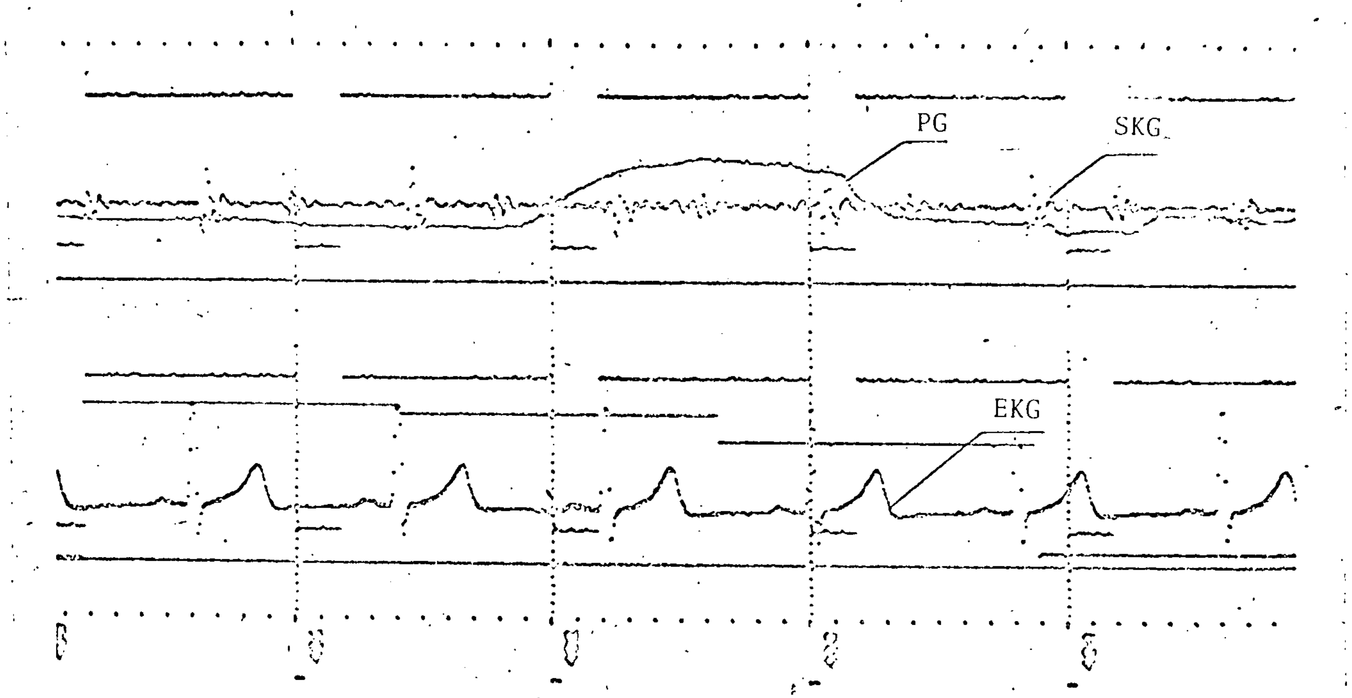

Figure 1. Samples of Telemetric Recordings of Physiological Parameters.
Explanation: PG, Pneumogram; SKG, Seismocardiogram; EKG, Electrocardiogram.

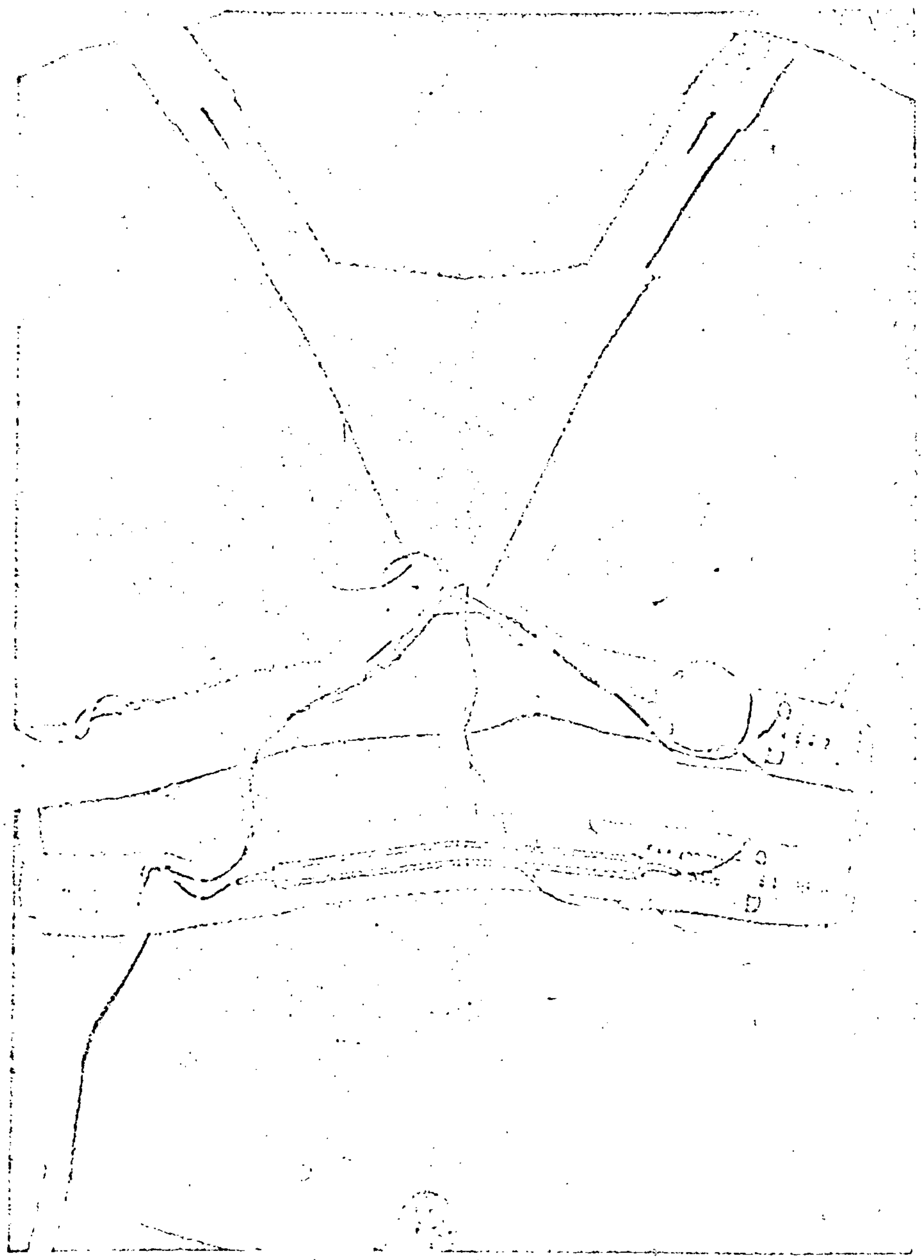

Figure 2. Physiological Sensors and System for Attaching Them.

This system included two sets of silver electrocardiographic electrodes, a seismocardiographic sensor and a respiration sensor, as well as elements intended for attaching these sensors and electrodes to the bodies of the cosmonauts. Leads terminating in connectors run from the sensors and electrodes. /22

One of the sets of electrodes (three box-type electrodes) was intended for recording electrocardiograms at rest and during limited motor activity of the cosmonauts; another (reticular electrodes) was used for recording electrocardiograms under conditions of increased motor activity.

The design of the box-type electrode makes it possible to use them for many days without adding paste. The current-carrying paste is in the box, one side of which forms the electrode itself and consists of a silver disk. There is a hole in the disk through which the paste emerges from the box onto a porous rubber pad placed between the electrode and the surface of the skin. By saturating the porous pad, the paste creates an electrical contact between the electrode and the skin.

"Active" box-type electrodes were mounted along the middle axial lines on the right and left, and the zero electrode was mounted between the medioclavicular and anterior axial lines on the right.

The reticular electrodes are round disks 12 mm in diameter made of silver foil, coated with a layer of silver chloride and mounted between vinyl chloride disks, one of which is placed against the skin and has openings for filling /23
the cavity of the electrode with current-conducting paste.

The reticular electrodes are fastened to the body by means of cement: the "active" electrodes are mounted one in the middle third of the chest and the other along the medioclavicular line at the level of the sixth rib; the zero electrode is attached to the lower third of the chest.

Attaching the electrodes in this fashion makes it possible to record the electrocardiogram regardless of what movements the subject makes. Under spaceflight conditions, the electrocardiogram was recorded using these electrodes attached to clothing inside the spacesuits of cosmonauts Ye. V. Khrunov and A. S. Yeliseyev while they were crossing from one ship to the other.

The seismocardiograms were recorded by means of an induction type sensor. This sensor is attached to the upper horizontal strap of a belt in the vicinity of the apical impulse in a special pocket. At rest, the seismocardiogram clearly shows two oscillatory complexes (cycles) which arise as a result of mechanical activity of the heart. During movement, the sensor of the seismocardiogram makes it possible to record actograms.

The resistance sensor is used for recording respiration; it is made in the form of rubber tubes connected in parallel and filled with carbon powder. This sensor makes it possible to record changes in the perimeter of the chest cavity, which develop in the course of respiration. The sensor is mounted on the lower horizontal strap of the belt, on the anterior surface of the chest wall.

The system for attaching the electrodes and sensors consists of two horizontal straps with buckles on the ends. The upper strap, on which the seismo- /24 cardiographic sensor and the box-type electrodes are mounted, has two elastic inserts, one in front and one in back, which keep the electrodes from shifting during respiratory movements and make it possible to reduce the errors in the electrocardiogram caused by the action of respiratory movements of the chest wall that disturb the stability of the contact between the electrode and the skin.

The buckles which are attached to the ends of the horizontal straps allow step-by-step increase or decrease of the tightness of the sensors against the body.

Elastic straps prevent the straps from sliding down. A triangular insert on the straps has a pocket in which the reticular electrodes are kept when they are not being used.

The electrical system of the "Soyuz" craft allows connection of the sensors and electrodes on the belt system of each cosmonaut to be connected to the input circuits of the medical monitoring system through special connectors whose receptacles are mounted on the chairs of the landing section, in the orbital compartment and in the spacesuits. The medical monitoring system makes it

possible to accomplish necessary amplification of the signals that come from the sensors and electrodes, generate the voltage levels corresponding to the running values of the duration of the heart cycle, and also to form certain signals of a service nature. A periodic monitoring system is used to transmit the information to Earth (with a 3-minute cycle and a transmission time of 1 minute for the information from one cosmonaut) when there are two or three cosmonauts aboard the craft and a system for continuous monitoring when
a single cosmonaut is in orbit. This made it possible to achieve uniform load- /25
ing of the telemetry channels for different crews on the spaceflight depending on the program and the makeup of the crew. The selected method of monitoring was realized technically by introducing into the medical monitoring system an electronic switch with gating from on-board timers.

In developing the apparatus for medical monitoring, it was necessary to find the most rational ways of accomplishing operational evaluation of the condition of the engineer-investigator and the flight engineer at the time they were making their changeover from one craft to the other.

In view of the fact that the individual stages of the program of the transfer were carried out while the craft were flying outside the zone of radio visibility with respect to ground measuring stations, when the pulse frequency was the only physiological parameter that could be recorded, it was desirable to transfer control during this time directly to the commanders who were able to make the necessary decisions in the light of available information and sufficient preparation should any changes arise in the rate of heart contractions and the body temperature of the astronauts in transit above permissible values.

The autonomous system of medical monitoring which allows evaluation of the condition of two cosmonauts in terms of pulse rate and body temperature was used despite the fact that the spacesuit dissipated the heat sufficiently well during heat simulation on Earth of the transfer program.

The following were included in the apparatus for autonomous medical monitoring: an amplifier-converter system, medical monitoring panel with necessary methods of obtaining information and rectal sensors for body temperature with systems of recording them.

The pulse frequency indicator was a device with a pointer mounted on the medical monitoring panel aboard the "Soyuz" craft. /26

The sensor for measuring body temperature, made in the form of a metal olive, which was inserted into the ampulla of the large intestine by the cosmonaut himself immediately prior to donning his spacesuit.

The body temperature indicators on the medical monitoring panel of the "Soyuz" craft were pilot lights with two modes of illumination, corresponding to the two threshold values of the parameter being measured (38.3°C and 39°C).

The "Soyuz-9" used the same medical monitoring apparatus as the preceding flights. However, the system of physiological sensors and the method of their use was subjected to a number of improvements in connection with the considerable increase in the flight duration.

During the flight, the electrocardiogram (EKG) was recorded from the "DS" leads, as well as the seismocardiogram (SKG), the pneumogram (PG) and the pulse rate of each of the crew members. All of the physiological sensors and electrodes were attached to the bodies of the cosmonauts by means of elastic cloth straps.

The most important improvements made in the methods of using physiological sensors were the following:

1) the fact that the cosmonauts themselves put on and removed the systems of physiological sensors;

2) in the case of continuous wearing of electrocardiographic electrodes, they were shifted daily to other parts of the skin so that the electrode was applied for one day to each area selected for this purpose and left the skin free for three days. The cosmonaut himself treated his skin with degreasing /27 liquid, applied the current-carrying paste to the electrodes, and also adjusted the degree of tightness of the elastic straps which fastened the electrodes and sensors.

This method has been used many times in a number of studies lasting a number of days, under conditions which simulated the special factors of spaceflight. The test results showed that it would be possible to use it aboard a spacecraft.

Physiological sensors were attached to cosmonauts A. G. Nikolayev and V. I. Sevast'yanov immediately prior to the beginning of the flight and were worn by them continuously during the first day and during the last three hours of the flight. During the rest of the time, the cosmonauts themselves put on the system of sensors and electrodes before starting the session for recording physiological parameters and removed them after the end of the session. During the flight, each of the cosmonauts put on the systems of physiological sensors no less than 25 times. In all cases, the quality of the recordings that were transmitted by telemetry and recorded on Earth was good. Cosmonauts Nikolayev and Sevast'yanov noted that putting on and taking off the systems of physiological sensors posed no difficulties for them and required no more than 5 to 10 minutes.

Both during the flight and after it, the crew members did not observe any special sensations or inflammatory changes in the skin associated with wearing the physiological sensors.

During the flight of the "Soyuz-9" spacecraft, for purposes of medical monitoring, the cosmonauts were required to carry out functional tests once every two days during the communications session. This test consisted of three series of stretchings of a rubber shock absorber, located behind the cosmonaut's back. In each series, he performed ten stretches (once every second). Intervals lasting 5 seconds were provided between the series. Recordings were made when the cosmonauts were at rest for one minute prior to the test, during the test itself, and for 2 minutes afterwards. According to the program, the cosmonauts had to perform this test once every two days. /28

In the course of the medical monitoring of comparatively short flights (up to 5 days) of the "Soyuz-3"-"Soyuz-8" spacecraft, the detection and transmission of physiological parameters by telemetry took place during practically the entire time that the spacecraft was in the range of radio visibility from the territory of the USSR. During the 18-day flight of the "Soyuz-9" spacecraft, this routine could be varied: the cosmonauts were able to take off and put on the system of belts for the physiological sensors and electrodes by themselves. The recording of physiological parameters from each cosmonaut took place no less than twice a day (in the morning and evening, according to the time frame aboard the craft). In addition, the flight program provided for days when the physiological parameters were recorded continuously all during the telemetry communication sessions for purposes of checking the dynamics of the daily periodicity.

CHAPTER III

RESULTS OF MEDICAL MONITORING AND MEDICAL TESTS IN FLIGHT /29

1. General Characteristics of the State of the Cosmonauts in Flight

All during the flight, the cosmonauts reported that they felt either excellent or good. A detailed analysis of the anamnesic data disclosed several interesting facts. Thus, cosmonaut G. T. Beregovoy reported that at the beginning of the flight he felt a slight increase in the pause between deciding to perform a motor act and the act itself, as well as a slightly manifest sensation of discomfort with sharp movements of the head. Beregovoy also reported that when he pressed his head against the bed with his eyes open he felt as though the ship were turning around. If he closed his eyes at this time, he felt that his body was turning. All of these sensations disappeared when he raised his head, when it was not in contact with the bed.

During the first 20 minutes in a state of weightlessness, Nikolayev felt "sensations indicating that the instrument panel was tilted upward 30°." In addition, cosmonauts Nikolayev and Sevast'yanov reported that when they tilted the upper part of the body or the head sharply when their legs were held firmly, they experienced sensations reminiscent of those which they felt on Earth under the influence of Coriolis accelerations.

When entering the state of weightlessness, practically all of the cosmonauts experienced subjective feelings of a rush of blood to the head. In the words of the cosmonauts, this sensation was about the same as that which a man feels under terrestrial conditions when he puts his head down and was accompanied by puffiness and reddening of the skin of the face, as well as reddening of the sclera of the eye. The intensity of this sensation of rushing of blood to the /30 head following the first hours of flight usually decreased and in many cases disappeared later on. However, when the individual concentrated on this sensation, he again experienced a sensation to a slight degree. The data reported by the cosmonauts created the impression that the severity of the sensation of rushing of blood to the head decreased noticeably when the cosmonauts assumed a position along the vector of the centripetal force (head toward the center of rotation) during the so-called turning of the craft. This sensation obviously had something to do with the redistribution of blood in the organism that is involved in weightlessness.

Cosmonauts Nikolayev and Sevast'yanov contributed some very interesting data on the details of performing movement in a state of weightlessness. At the beginning of the flight, the cosmonauts reported, they experienced some difficulty in judging the muscular effort required to perform appropriate movements which in many cases turned out to be incorrect. However, by the third or fourth day the cosmonauts had acquired the necessary precision in their movements, which evidently indicates the development of a new motor stereotype. Pushing away with the aid of their legs, the cosmonauts were easily able to adjust the positions of their bodies and move in the necessary direction, giving practically no thought to controlling these movements. Sevast'yanov reported that he was easily able to catch and move around individual objects with the aid of his legs.

An analysis of the radio conversation data, the reports of the cosmonauts regarding their sensations and the television observations made it possible to /31
ascertain the behavior of the cosmonauts all during flight and to conclude that it was correct and adequate for concrete situations. The cosmonauts' speech was sharp and clear. The data from the television observations indicate that they performed their movements completely and no disruption of coordination of movement was observed. Television and radio interviews took place with active participation of all crew members. The answers to the questions followed immediately and were adequate. The working ability of all crew members remained at a high level all during the entire flight. This was demonstrated most markedly by the performance of complex maneuvers including rendezvous and docking, performance of numerous experiments as well as successful extravehicular activity.

However, after carrying out complex experiments and performing the work of the day, the cosmonauts sometimes noticed slight fatigue, which disappeared completely after they had slept. Sensations of thirst during flight were usually slightly reduced. Natural functions usually were not disturbed although the stool was not always regular.

Thus, the first act of defecation for the crew members of the "Soyuz-9" came on the fourth day of the flight, and each day thereafter as a rule. Urination was regular, two to five times daily.

After several days of adaptation, sleep was deep during the 18-day flight; it lasted 7 to 9 hours and "always brought freshness and good humor." The crew members fell asleep rapidly about the same as on Earth. Sevast'yanov preferred to sleep on his cot without being tied in. On the first day of the flight, he sometimes fell asleep for 10 to 15 minutes at a time during his free time at his place of work.

2. Changes in Principal Physiological Parameters During Flight /32

As a result of the analysis of the medical information, certain general aspects of the changes in the physiological parameters under the influence of factors and conditions of flight were observed; this was especially true of such an integral indicator as the frequency of cardiac contractions.

A quantitative evaluation of the changes in the frequency of cardiac contractions, respiration frequency and principal parameters of electrocardiograms did not reveal any differences in the dynamics of these parameters in the various cosmonauts during the active participation in the flight and during the landing. In studies made during the 5-minute period of preparation, all cosmonauts showed a sharp increase in the rate of cardiac contractions and a shortening of the time indices of the electrocardiogram. These changes became still more pronounced during the first and second minutes of the flight during active participation and later showed a tendency to decrease. The most pronounced changes in the physiological parameters were noted during the landing.

After the insertion of the spacecraft into orbit, the frequency of cardiac contractions and other physiological parameters showed a tendency toward a slow normalization. Among the crews of the "Soyuz-4", "Soyuz-5", "Soyuz-9" spacecraft, the frequency of cardiac contractions reached preflight values after

5-6 revolutions, and then (except for periods of work in the depressurized sections of the craft and in deep space) remained at a much lower average level than in the preflight period, or did not differ from it (Figures 3 and 4).

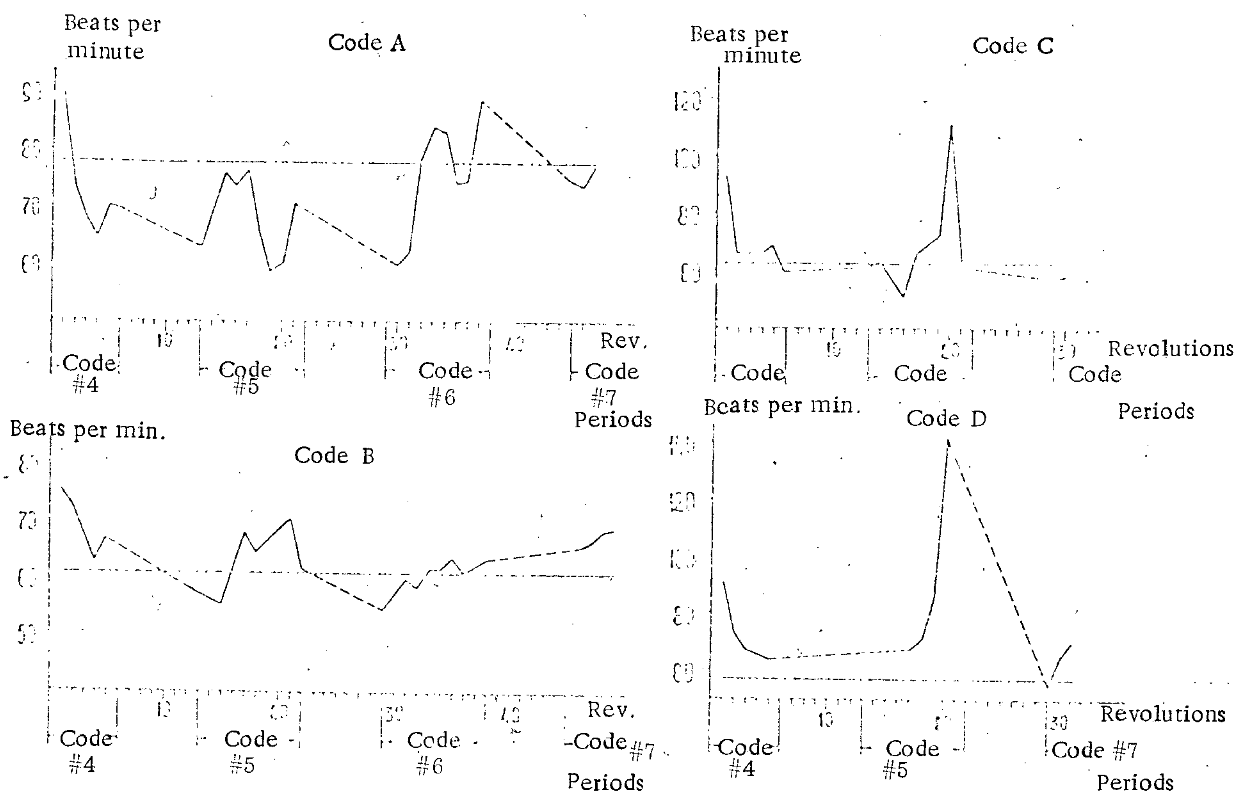

Figure 3. Dynamics of the Frequency of Cardiac Contractions Among the Crew Members of the "Soyuz-4" and "Soyuz-5" Spacecraft During an Orbital Flight. The broken line shows the actual values of the physiological parameter during the revolutions; the horizontal line represents the average values of the parameters during the preflight period; Code number 4, initial period of orbital flight (1-7 revolutions); 1, 2, 3, first (13-23 revolutions), second (29-39 revolutions), third (45-55 revolutions) periods of orbital flight; Code number 7, prelanding period of orbital flight (last 3-4 revolutions of the flight); Code A, Cosmonaut V. A. Shatalov; Code B, Cosmonaut B. V. Volynov; Code C, A. S. Yeliseyev; Code D, Cosmonaut Ye. V. Khrunov. Code number 5, first period of orbital flight; Code number 6, second period of orbital flight.

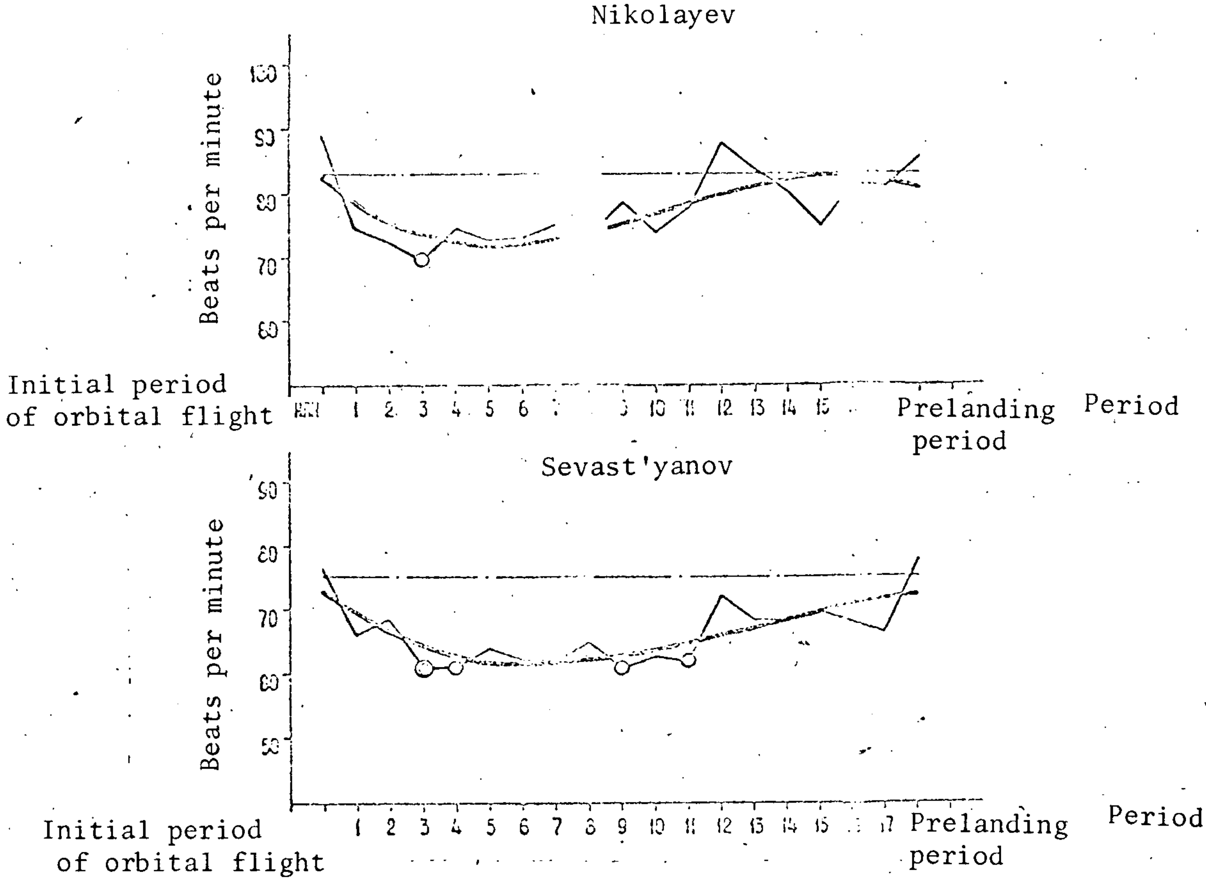

Figure 4. Dynamics of Average Values of Frequency of Cardiac Contractions of the Crew Members of the "Soyuz-9" Spacecraft During Orbital Flight. Captions: The broken lines represent the actual average values of the physiological parameters at various periods of orbital flight; the horizontal straight lines, dot-dash, represent the average values of the preflight period in a state of excitement; the straight lines or parabolas represent smoothed data characterizing the trend of the changes in physiological parameters in orbital flight; Code number 1, initial period of orbital flight; 1, 2, 3,...17, 1-17 periods of orbital flight; Code number 2, prelanding; one small circle (o), average value of parameter in a given period, statistically significant ($P \leqslant 0.05$) differing from the average value of the preflight period: a small circle inside a large circle (◎), average value of a parameter in a given period, statistically significant ($0.05 < P \leqslant 0.10$) differs from the average value of the preflight period.

In the case of cosmonauts Nikolayev and Sevast'yanov, the frequency of the cardiac contractions during the last third of the flight showed a tendency toward an increase and practically reached preflight values (Figure 4). /35

The reaction as far as the frequency of cardiac contractions was concerned to the standard physical stress did not show any significant changes in the two cosmonauts during the flight (Table 5).

TABLE 5. CHANGES IN THE FREQUENCY OF CARDIAC CONTRACTIONS DURING A FUNCTIONAL TEST IN FLIGHT

Day of the flight	A. G. Nikolayev			Day of the flight	V. I. Sevast'yanov		
	Before tests	Average of 3 series (% of original)	2 min of recovery (% of original)		Before tests	Average of 3 series (% of original)	2 min of recovery (% of original)
2	72	140	115	1	70	112	100
7	75	119	101	3	64	117	98
8	66	132	114	5	65	120	100
10	70	121	109	7	63	119	105
12	77	130	105	9	62	116	100
13	72	118	105	12	63	117	108
14	80	113	90	14	63	111	94
16	86	116	100	15	68	113	94
17	85	113	104	16	69	127	101
				17	79	111	90

Note: During the preflight period, the frequency of cardiac contractions prior to the tests, during its performance (average value for three series) and after 2 minutes of recovery were as follows: for A. G. Nikolayev, 78 beats per min, 131%, 108%; for V. I. Sevast'yanov, 68 beats per minute, 147%, 106%. However, these data are incomparable (without appropriate corrections for weight) with those obtained in flight.

The dynamics of the electrosystole and the systolic parameter during the orbital flight, although it was determined by the frequency of the cardiac contractions, nevertheless the values of these parameters and the deviations from their required values usually either did not differ from the preflight levels or were less than the latter [sic]. The duration of the intraventricular conductivity and the period of asynchronous contraction in the crew members of the "Soyuz-4" and "Soyuz-5" craft in all cases exceeded the original values to some degree (Figure 5).

The duration of the electromechanical and mechanical systole changed in close relationship to the frequency of the cardiac contractions. Their average values as well as the difference between them and the required values, in all the cosmonauts aboard the "Soyuz-4" and "Soyuz-5" spacecraft, exceeded the set values by a statistically significant value (Figure 6). In conjunction with these changes in the electrical and mechanical systole, the mechanoelectrical coefficient also was considerably in excess of the values that were recorded during the preflight period.

In the case of cosmonauts Nikolayev and Sevast'yanov, the duration of the intraventricular conductivity, the phase of asynchronic contraction and the level of the difference between the actual and required values of mechanical systole also exceeded the background values, although this difference was not statistically significant during the entire time of the flight (Figures 7, 8). /39

During preparation for and performance of the space walk, there was a sharp, statistically significant increase in the frequency of cardiac contractions, rate of respiration and systolic parameter and a shortening of the time indicators of the electrocardiogram and seismocardiogram. In addition, there was a decrease in the magnitude of the mechanoelectrical coefficient and the duration of the first and second oscillatory cycles of the seismocardiogram.

The medical monitoring panels of the spacecraft commanders had no warning signals to limit the working operations during the transit. It should be pointed out that the changes in physiological parameters during the period of preparation and performance of the space walk were not unexpected and had no significant difference with respect to the data recorded for other cosmonauts.

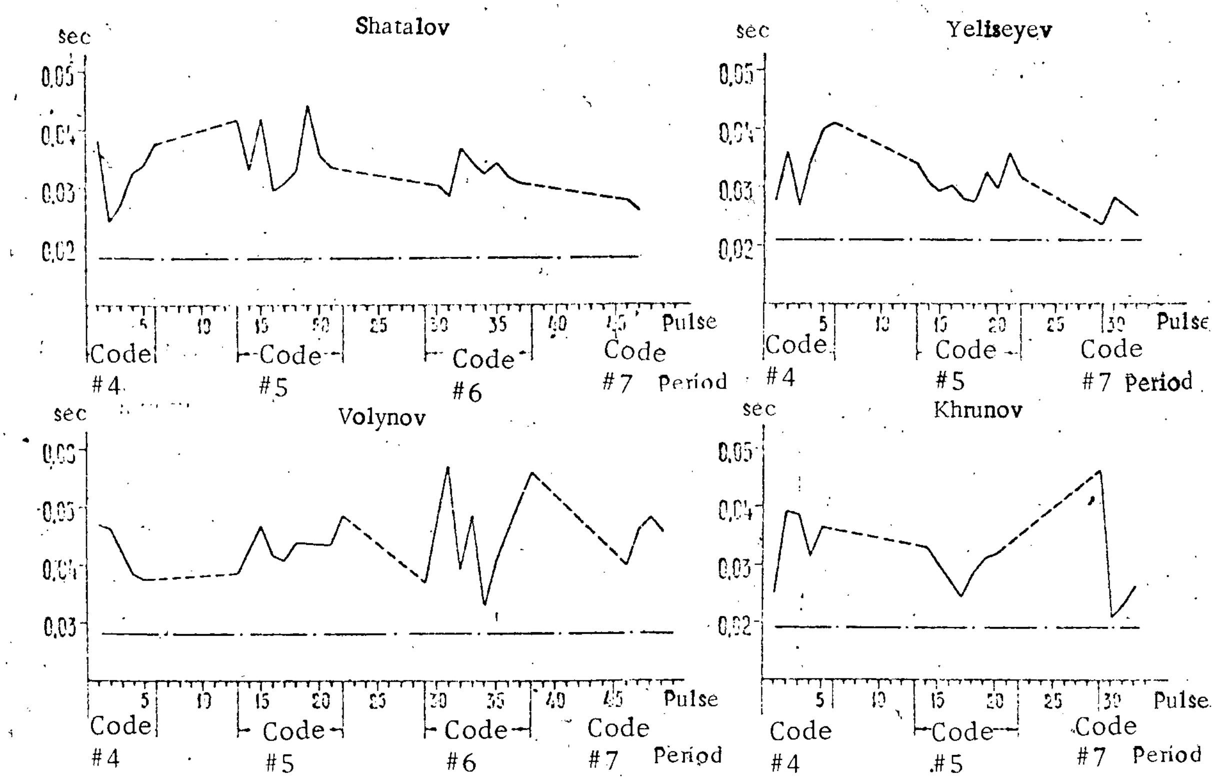

Figure 5. Dynamics of Average Values of Duration of the Period of Asynchronous Contractions in the Crew Members of the "Soyuz-4" and "Soyuz-5" Spacecraft During Orbital Flight.

Data on the changes in the physiological parameters of the crew members of the "Soyuz-3", "Soyuz-6" - "Soyuz-8" spacecraft differed slightly from the results that were obtained during the manned spaceflights of the "Soyuz-4", "Soyuz-5", and "Soyuz-9". The frequency of the cardiac contractions during the flights of these spacecraft, although they had a tendency toward a slow return to preflight value, did in fact exceed them in the case of cosmonauts Beregovoy, Kubashov and Filipchenko practically all during the flight (Figure 9). In the case of the other crew members, except for Yeliseyev, the frequency of cardiac contractions during flight showed no significant differences with respect to preflight data. The duration of the period of asynchronous contractions during the flight also did not vary from the preflight values and sometimes was even less (in the case of Beregovoy and Filipchenko) (Figure 10). Nor was there an /45 increase in the difference between the actual and required values of the electromechanical and mechanical systole in flight during excitement in comparison to the data for the preflight period (Figure 11).

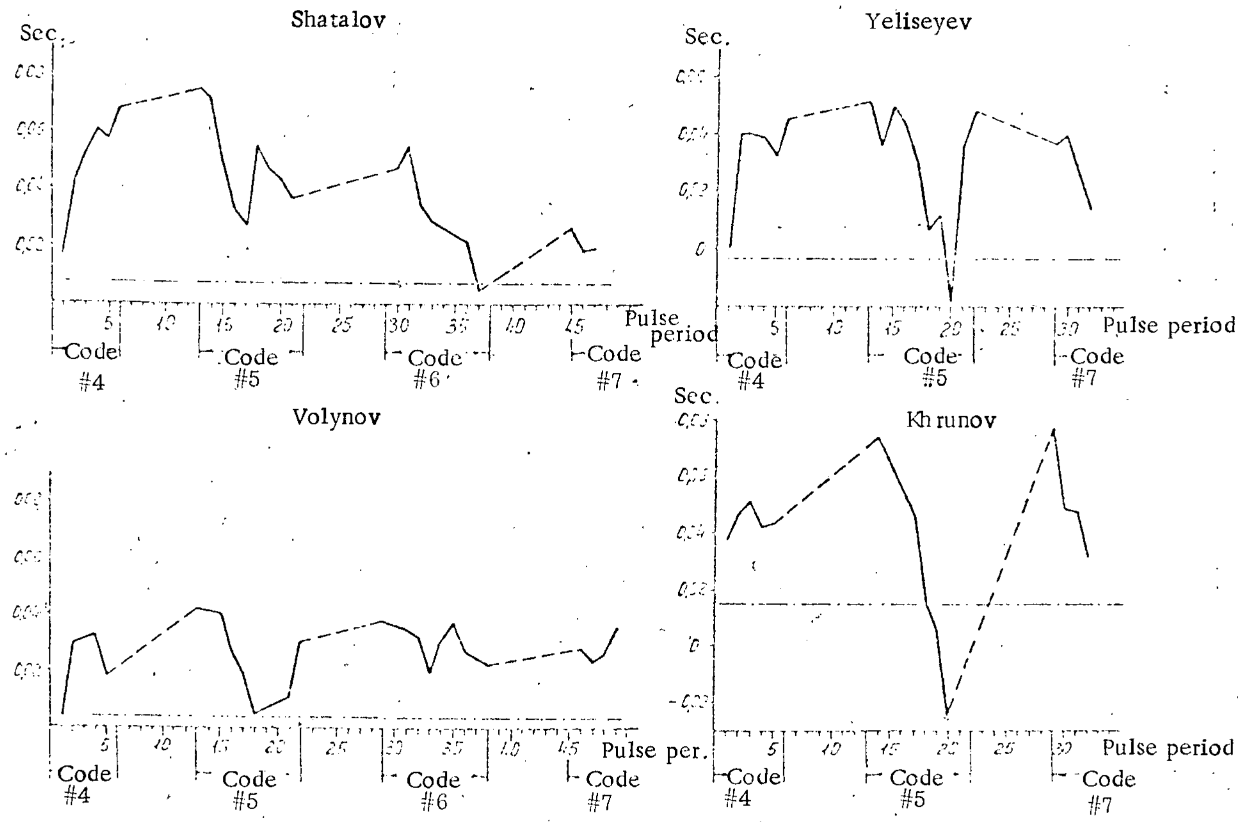

Figure 6. Dynamics of the Difference Between the Actual and Required Values for Electromechanical Systole Among the Crew Members of the "Soyuz-4" and "Soyuz-5" Spacecraft During Orbital Flight.

The characteristics described for the changes in the physiological parameters during flight for the crew members of the "Soyuz-3", "Soyuz-6" - "Soyuz-8" spacecraft are apparently linked to neuro-emotional stress, caused by performing numerous maneuvers and other complicated operations.

Hence, the changes that were observed during orbital flight in the frequency of cardiac contractions, the parameters of the electrocardiogram and the seismocardiogram indicate a functional adjustment of the circulatory apparatus caused both by the characteristics of regulation under specific conditions and by changes in the hemodynamic relationships. In addition, an analysis of the information obtained regarding the state of the cardiac activity in orbital flight indicates that there were no disturbances of the contractile function of the myocardium.

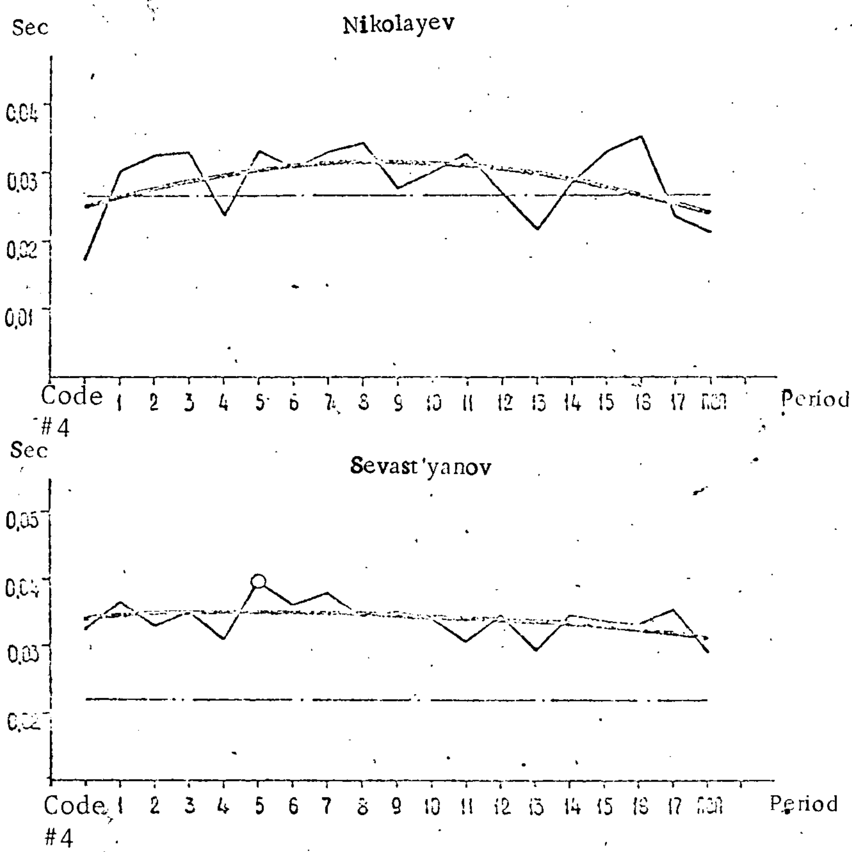

Figure 7. Dynamics of the Average Values of the Duration of the Period of Asynchronous Contractions for the Crew Members of the "Soyuz-9" Spacecraft During Orbital Flight.

Data that were obtained in the course of the "Soyuz" program indicate that certain physiological parameters in man during spaceflight undergo regular and predictable changes. An example might be the frequency of cardiac contractions. Experience gained in performing medical monitoring of the condition of cosmonauts during flight provided considerable information on this parameter.

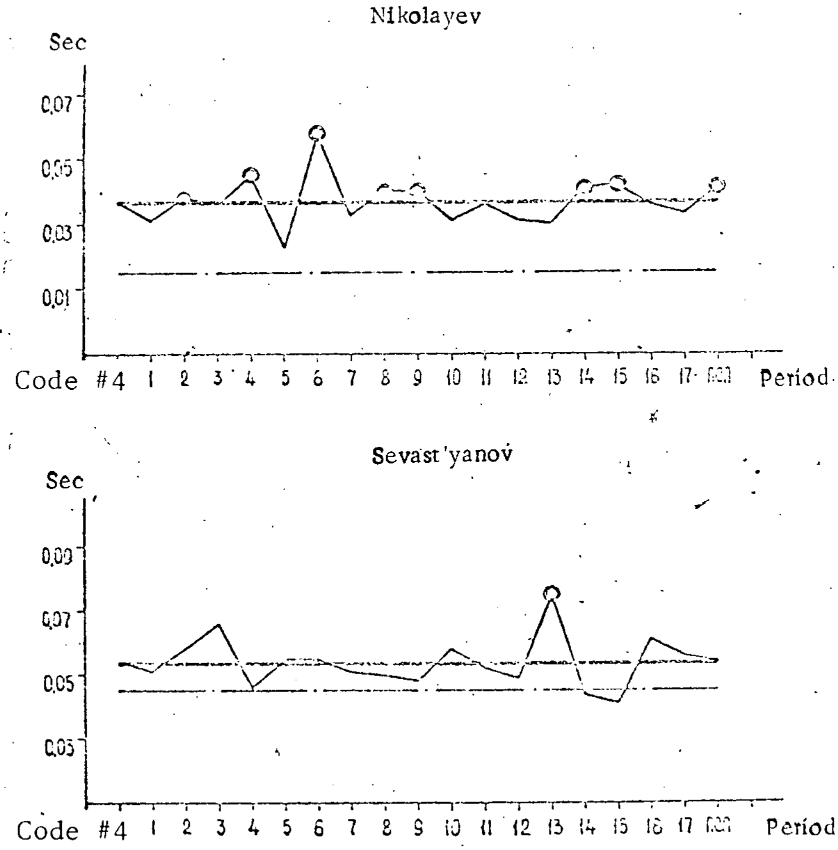

Figure 8. Dynamics of Difference Between Actual and Required Values of Mechanical Systole in the Crew Members of the "Soyuz-9" Spacecraft During Orbital Flight.

Figure 12 and Table 6 show the dynamics of the frequency of cardiac contractions in the crew members of the "Soyuz" spacecraft prior to launching, during active participation in the flights, during various periods of exposure to weightlessness and during the landing of the spacecraft. The graph clearly shows the following:

--the role of emotional stress;

--comparatively slight increase in the pulse frequency during the active mode (it remains to be seen whether this can be explained by the action of acceleration or is a result of emotional stress);

--normalization of the pulse frequency after five or six revolutions;

--a considerable increase in the pulse frequency during the landing of the spacecraft.

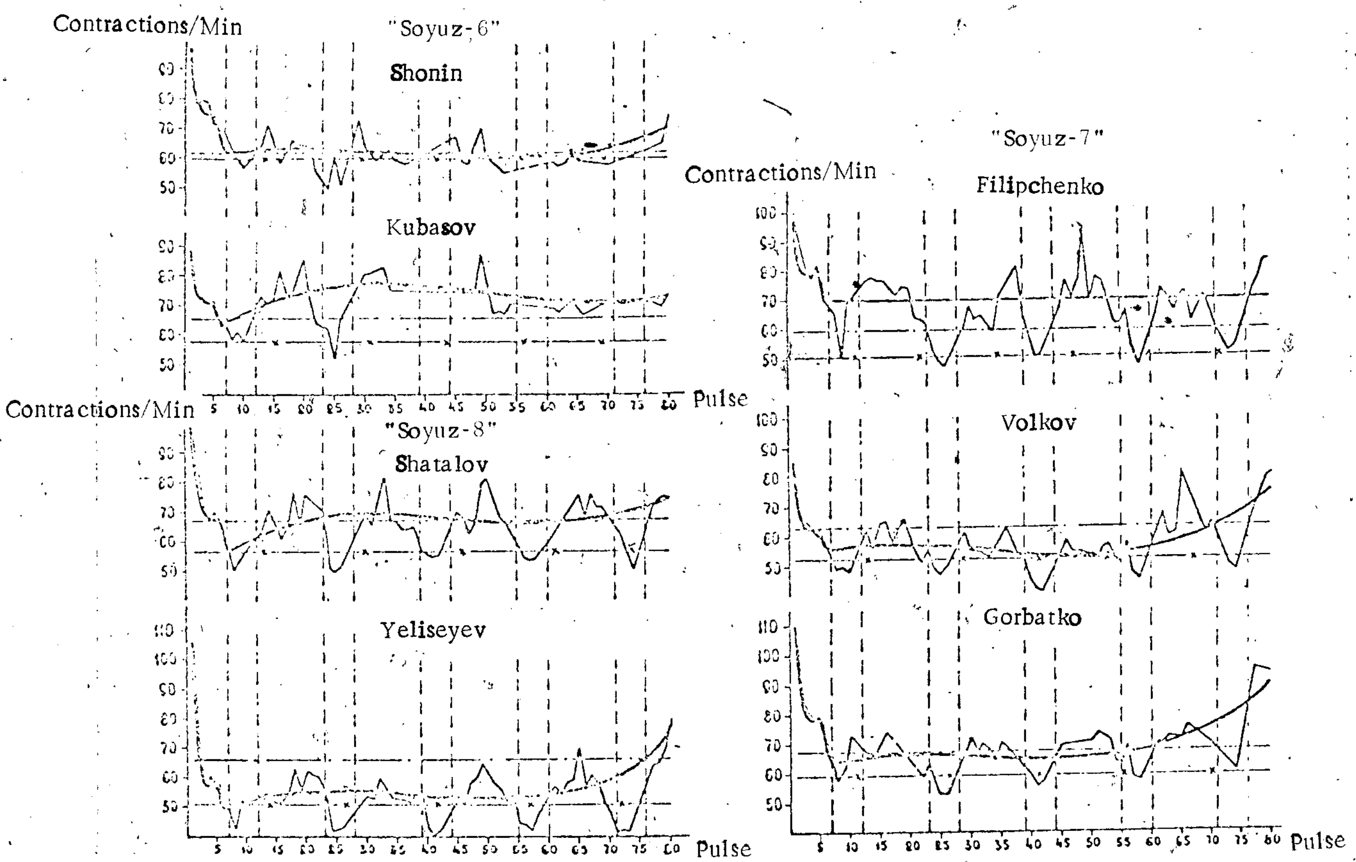

Figure 9. Dynamics of the Frequency of Cardiac Contractions in the Crew Members of the "Soyuz-6" - "Soyuz-8" Spacecraft During Flight. Symbols: B, Cosmonaut G. S. Shonin; C, Cosmonaut V. N. Kubasov; H, Cosmonaut A. V. Filipchenko; I, Cosmonaut V. N. Volkov; J, Cosmonaut V. V. Gorbatko; E, Cosmonaut V. A. Shatalov; F, Cosmonaut A. S. Yeliseyev; horizontal lines (dotted), average values of pre-flight period during period of excitement; dots and crosses, ditto, during sleep; parabola, smoothed values characterizing trend of changes in physiological parameters during orbital flight; revolutions 7-12, 23-28, 39-44, 56-60, marked by vertical lines, correspond to the sleeping periods of the cosmonauts.

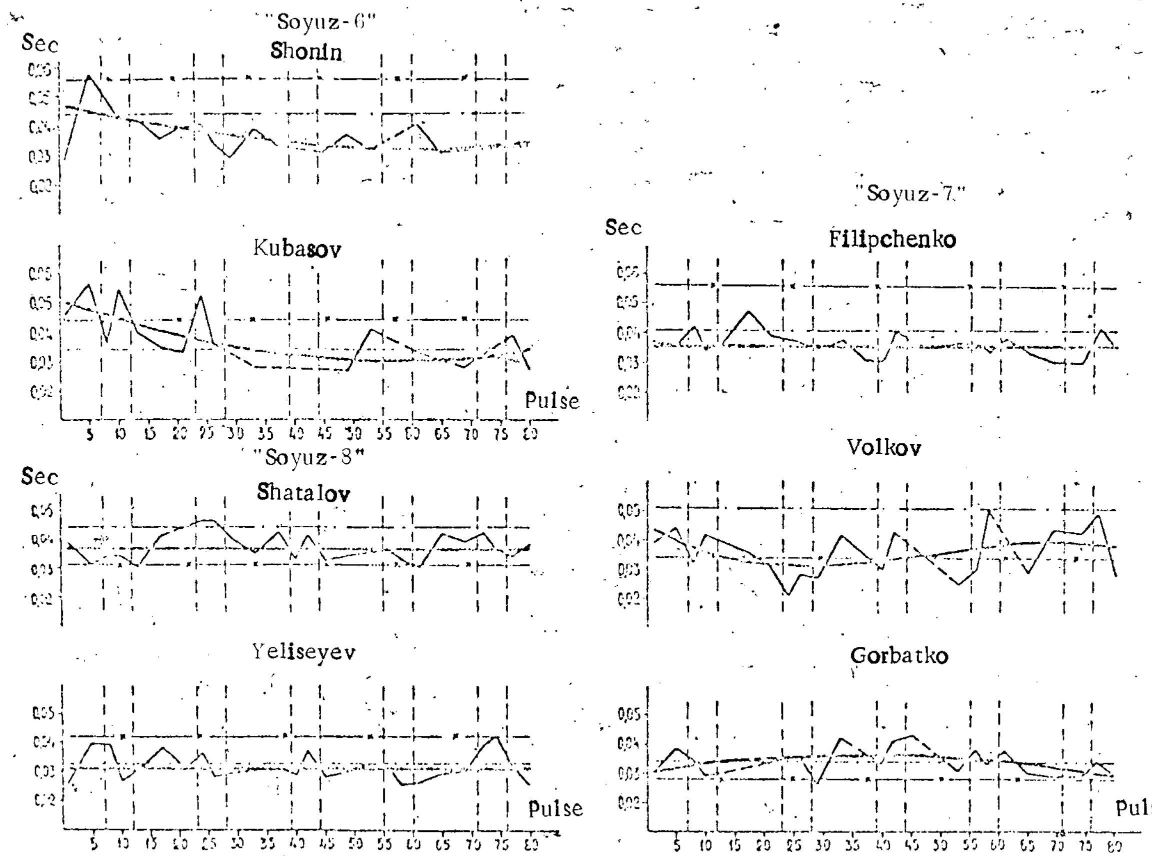

Figure 10. Dynamics of the Duration of the Period of Asynchronous Contractions in the Crew Members of the "Soyuz-6" - "Soyuz-8" Spacecraft in Orbital Flight.

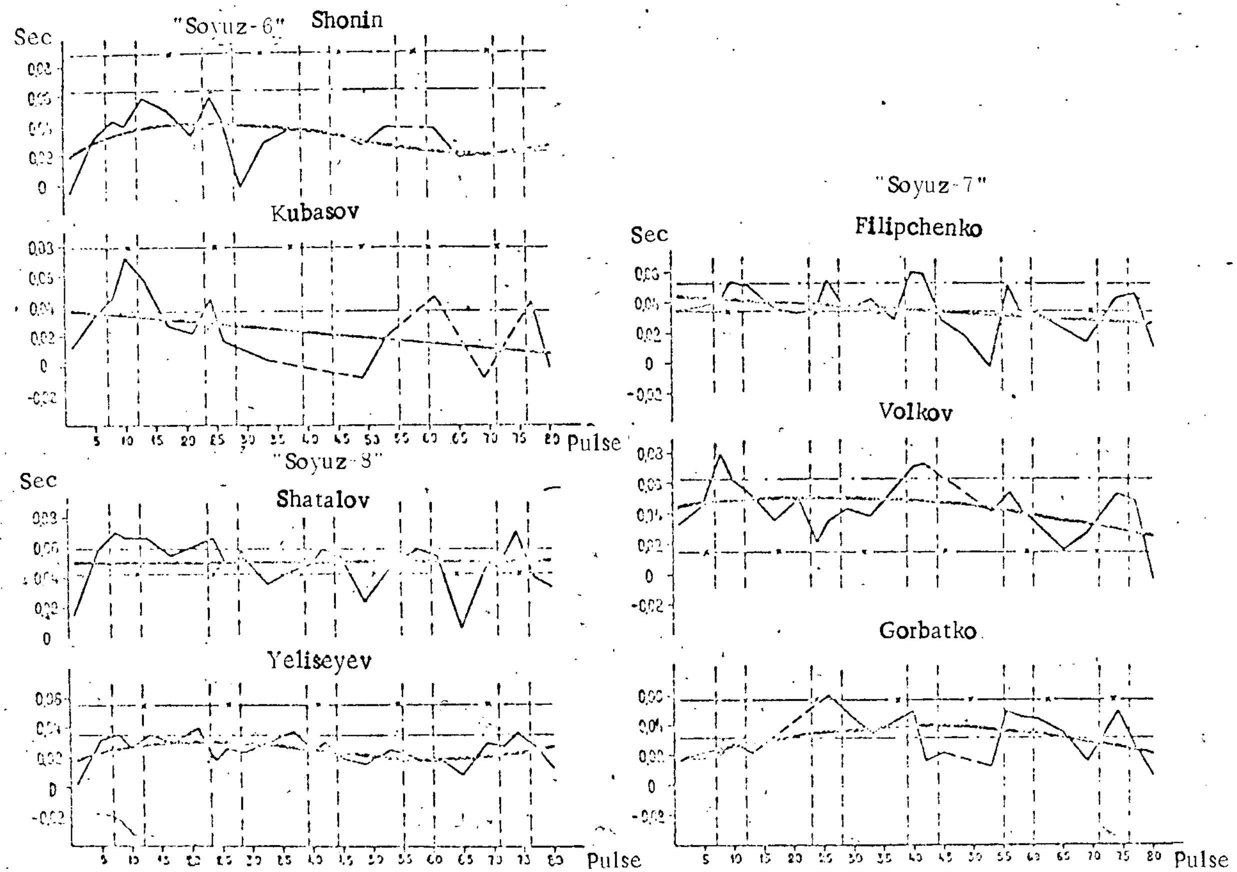

Figure 11. Dynamics of the Difference Between Actual and Required Values of Electromechanical Systole in the Crew Members of the "Soyuz-6" - "Soyuz-8" Spacecraft During Orbital Flight. Symbols are the same as Figure 9.

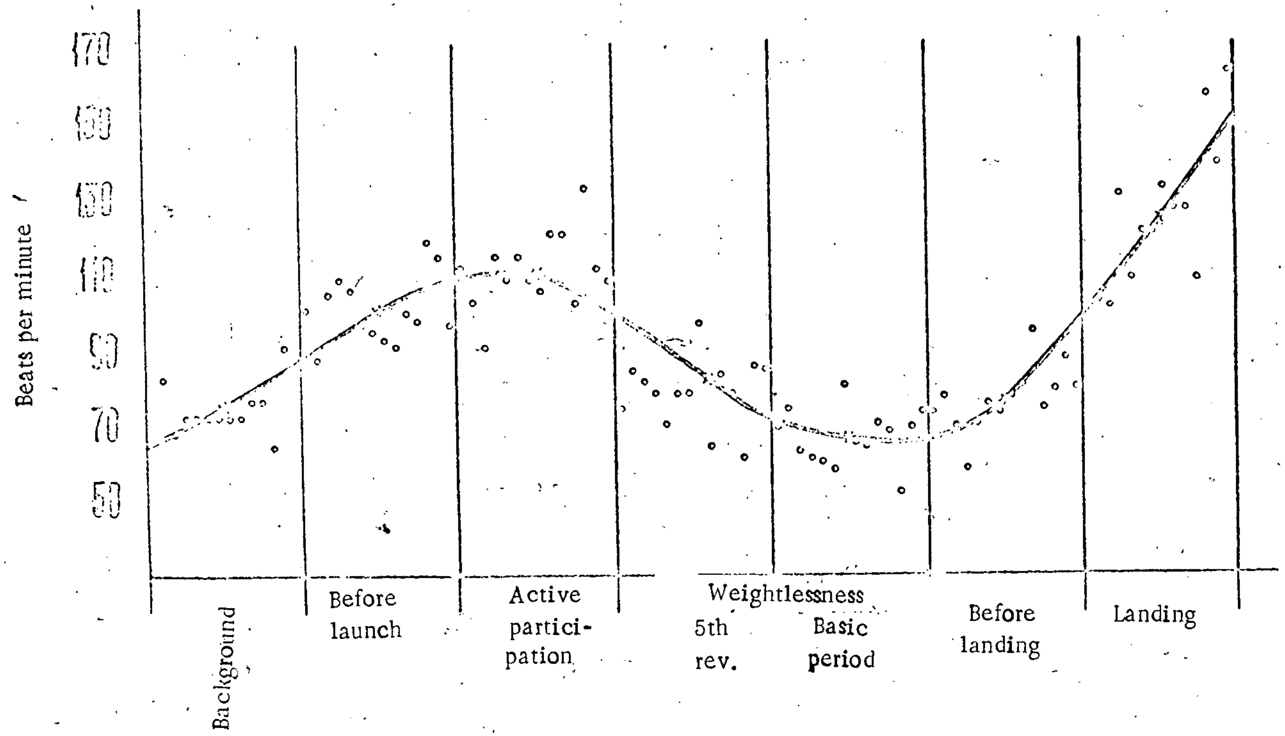

Figure 12. Average Values of the Frequency of Cardiac Contractions for 14 Cosmonauts--Crew Members of the "Soyuz-3", "Soyuz-9" During the Preflight Period and During Various Stages of the Flight.

TABLE 6. AVERAGE VALUES FOR THE FREQUENCY OF CARDIAC CONTRACTIONS AT VARIOUS PERIODS OF THE FLIGHT.

	G. T. Beregovoy	V. A. Shatalov	B. V. Volynov	A. S. Yeliseyev	Ye. V. Khrunov	G. S. Shonin
Preflight period:						
Day (rest)	60	78	61	68	57	62
Night (sleep)	52	58	47	52	45	60
Preflight period	91	87	76	82	86	91
Active participation	98	91	79	102	95	98
Weightlessness:	81	73	70	71	72	79
2nd revolution	81	73	73	66	73	78
4th "	77	64	63	66	65	78
5th "	73	71	67	69	64	71
2nd day	67	68	63	68	92	64
3d day	66	76	60	--	--	63
5th day						
10th day						
15th day						
17th day						
In deep space				112	143	
Free landing period	69	75	67	58	63	68
Landing segment	87	92	79	107	84	94
After landing, day (rest)	74	--	--	--	--	60

TABLE 6. (APPENDIX I)

	V. N. Kubasov	A. V. Filipchenko	V. N. Volkov	V. V. Gorbatko	V. A. Shatalov
Preflight period:					
Day (rest)	66	60	63	68	67
Night (sleep)	57	50	52	59	57
Preflight period	87	86	80	96	93
Active participation	96	95	100	107	96
Weightlessness:	74	81	67	84	75
2nd revolution	76	80	66	87	72
4th "	70	78	63	78	67
5th "	72	82	60	79	70
2nd day	74	73	60	67	68
3d day	80	68	57	68	68
5th day	71	69	65	71	70
10th day					
15th day					
17th day					
In deep space					
Free landing period	71	78	75	94	73
Landing segment	97	103	123	107	82
After landing, day (rest)	72	72	84	80	66

TABLE 6. (APPENDIX II)

	A. S. Yeliseyev	A. G. Nikolayev	V. I. Sevast'yanov
Preflight period: Day (rest) Night (sleep)	66 51	83	75
Preflight period	100	101	87
Active participation	125	99	99
Weightlessness:	67	89	77
2nd revolution	68	82	82
4th "	60	--	67
5th "	56	--	78
2nd day	57	75	66
3d day	53	72	68
5th day	57	74	61
10th day		79	61
15th day		80	68
17th day		81	67
In deep space			
Free landing period	69	86	78
Landing segment	122	107	122
After landing day (rest)	68	72	76

3. Investigation of Vestibular Functions During Flight /51

Experiments in ground simulation of experiments by Soviet and foreign investigators and analyses of the results of launchings of biological satellites, as well as experience from manned spacecraft flights, indicate a complex influence of spaceflight factors on the condition of the vestibular analyzer.

The first steps in the study of the function of the vestibular analyzer in space were the studies performed aboard the "Vostok" and "Voskhod" spacecraft. On these flights, attempts were made to study the nature of the changes in the vestibular function in the state of weightlessness by analyzing the postural reflexes and motor reactions with the aid of specially derived tests. The principal results of these investigations were undoubtedly the relationship between the resistance of the vestibular apparatus to the action of adequate stimuli and the ability to withstand spaceflight. The materials from these studies formed the basis of the development of a new system of vestibular selection and also determined the advisability of special preparation of cosmonauts by means of active and passive training of the vestibular analyzer.

As the "Soyuz" program was organized, considerable emphasis was placed on studies aimed at clarifying a number of aspects of the vestibular problem.

These included the following:

1. Continuation of the study of the functional state of the vestibular analyzer under conditions of weightlessness.

2. A clarification of the role of Coriolis accelerations under conditions of weightlessness and the significance of their cumulative effect in the origin of the symptoms of vegetative disturbances.

3. Clarification of the physiological mechanisms of spatial disturbances as evidence of the disruption of the systemic function in the interaction of analyzers. /52

4. A general overall evaluation of an artificial force of gravitation generated by rotating the spacecraft, from the standpoint of its positive and negative effects on the condition and working ability of the cosmonauts.

5. Further accumulation of factual data involving comparison of vestibular stability, determined by ground experiments and ability to withstand spaceflight for the purpose of studying the possibility of predicting the nature of vestibular disturbances on flights of varying duration.

One of the methods of studying the functions of the vestibular analyzer is the method of graphic recording of the vestibular-signal reflex by means of the so-called vertical letter.

In analyzing the writing of the vertical letter, we found an increase in the magnitude of the slope angles by almost three times in comparison to terrestrial experiments. This indicates an increase in the vestibular-tonic reflex, which shows up under the influence of much lower values of adequate stimulus than under terrestrial conditions (rotation of the craft at an angular velocity of 3° per second). These data indicate an increase in the reactivity of the cupulo-endolymphatic system of the vestibular analyzer to Coriolis acceleration under conditions of weightlessness.

For the purpose of studying the role of Coriolis accelerations in the performance of vegetative reactions during motor activity of cosmonauts in flight, we used a specially devised set of calibrated motor stresses with consideration of the direction of action of the Coriolis forces, as well as the volume and the speed of movement.

The calculated values for the Coriolis acceleration acting on the semi- /53
circular canals under the flight conditions of spacecraft of the "Soyuz" type indicate that they do not exceed threshold values (0.008 cm/sec^2). In addition, a significant motor activity during rotation of the craft creates a certain cumulative effect accompanied by subjective sensations reminiscent of the state of seasickness. A direct relationship has been established between the magnitude of the Coriolis accelerations and the degree of severity of the vegetative reactions. This in particular may be explained by the increase in the reactivity of the cupulo-endolymphatic apparatus to the angular and Coriolis accelerations under conditions of weightlessness, which was observed in the course of the study of the vestibular-somatic reflexes by means of the method of the vertical letter.

All of the cosmonauts stress the importance of taking into account the negative influence of the cumulative effect of various accelerations during flight and in this regard expressed their categoric opinions of the considerable significance of a high level of vestibular resistance and the necessity for further improvement in methods of selection and systems of training.

Among the information on the flight which was obtained from the cosmonauts, considerable interest was aroused by the reports of the significance of visual and tactile control in the spatial orientation during spaceflight. All of the cosmonauts remarked that during the flight, under conditions of total darkness or with their eyes covered, they experienced a sensation of disorientation in space. Only tactile information gives an idea of the position of the body in the cabin. These observations support the opinion of an important role being played in the development of spatial disturbances under weightlessness by changes in impulsation from the gravireceptors of the otolith apparatus and other receptor systems. /54

As we know, certain Soviet and American cosmonauts have observed illusory sensations of movement of surrounding objects or changes in the position of the body during flight, even having the illusion of being upside down. The problem of spatial orientation of man in space is not only of theoretical interest, but has purely practical value, especially in determining what is "up" and what is "down" in the spacecraft, the position of the body itself with respect to objects and the axes of the craft, and also objects outside the cabin (Earth, Moon, Sun, stars) and what is particularly important in maneuvering with respect to other objects in space, docking, circumnavigation, etc.

One method of studying the function of spatial orientation of man in space and its dependence on the function of gravireceptors in the otolith apparatus consists in studying the subjective visual and nonvisual, i.e., postural spatial coordinates. The method makes it possible to get some idea of the state of the gravireceptor function of the vestibular apparatus and the system of the "vestibular-visual analyzer". Errors in determining the coordinates in two dimensional space increase with disruption of interaction with regard to the joint operation of these analyzer systems. The degree of imbalance in coordination of their activity determines the tendency of the individual toward illusory sensations and gives an idea of the role of the vestibular analyzer in this phenomenon.

Studies have shown that adaptation to the absence of a sensation of a gravitational vertical develops very rapidly during spaceflight. The number of systematic errors in determining the visual vertical and horizontal coordinates in flight increases insignificantly in comparison to terrestrial experiments. Errors in determining postural (nonvisual) coordinates are somewhat more pronounced.

Apparently, otolithic gravireceptors do not play the coordinating and critical role in the formation of spatial orientation under conditions of spaceflight. /55

The close functional relationship between the tactile and proprioceptive analyzers apparently increases in the state of weightlessness and constitutes the basis for the construction of a new system of interaction of analyzers, compensating partly for the loss of gravitational function of the otoliths with exclusion of vision.

However, these considerations are only valid as they apply to space in a closed cabin with familiar orientation points.

At the same time, the absence of any kind of information regarding the spatial position in spaceflight makes it impossible in general to determine the coordinates and the position of the body in space. Therefore, we can say that orientation in space is accomplished primarily by the visual analyzer.

Studies have also shown that the maximum value of the centrifugal force of 0.001 g which develops when the craft rotates is insufficient for forming equivalent sensations to the terrestrial "up" and "down." However, changes in the direction of action of the vector of centrifugal force do have subjective limitations. Thus, a centrifugal force with the magnitude indicated above, acting in the pelvis-head direction, causes pronounced unpleasant sensations of a flow of blood to the head. Changing the position of the body with a consideration of the action of centrifugal force in the head-pelvis direction considerably reduces the sensation of the flow of blood to the head.

The performance of studies in this connection will make it possible to establish the significance of the levels of artificial gravity that have been /56 developed during the rotation of spacecraft and to evaluate the positive and negative role which it plays as a function of the position of the body and the nature of movement of the cosmonauts.

The data that have been obtained indicate an important role for the vestibular analyzer and the formation of various unpleasant reactions, caused by the action of spaceflight factors on the human organism, making it necessary to expand studies in this area.

Hence, studies of the vestibular analyzer at the present time are of particular importance not only as part of the program of preventing symptoms of seasickness and solving problems related to the creation of artificial gravitation, but also for the purpose of ensuring normal working ability and safety of the cosmonauts under the conditions of a long flight.

4. Biological Studies

Biological experiments were also performed aboard the "Soyuz" spacecraft, together with the medical tests and observations. However, they were less intensive than those aboard the "Vostok", "Voskhod" and "Zond" spacecraft, and therefore no important new data were obtained. Nevertheless, these experiments were a further step in carrying out the program of biological studies in space.

The general purpose of the experiments was to record and study the changes in the structures and functions of certain biological objects under the influence of weightlessness, ionizing radiation and other spaceflight factors. /57
The experiments constituted a continuation of past efforts, in the sense that the objects and methods of investigation were chosen so as to permit comparison of the results with the data from tests aboard the "Vostok", "Voskhod", "Kosmos" and "Zond" spacecraft.

The general program for performing the experiments consisted in determining the differences between investigated parameters of biological objects carried on the flight and those in the laboratory in postflight studies.

The following biological objects were used in experiments aboard the "Soyuz" spacecraft:

1) turtles,
2) Chlorella,
3) lysogenic bacteria, and
4) dry seeds of various types and kinds of plants.

The data that were obtained by carrying out biological experiments aboard the various "Soyuz" spacecraft agree and do not differ in principle on the results of experiments that were performed earlier on other spacecraft. For the sake of an example, we can use the results that were obtained in experiments with Chlorella, dry plant seeds aboard the "Soyuz-5"-"Soyuz-7", turtles and lysogenic bacteria aboard the "Soyuz-7". In the experiment with Chlorella, it was found that among the plants on the flight there was a considerable decrease in the viability of the cells (Table 7). Both the experimental and control plants showed a decrease in survival rate, due mainly to the death of small cells, which is evidently due to the long storage of the cell culture in an inactive state. This effect was considerably reinforced in the material aboard the spacecraft, apparently by temperature and dynamic factors. This answer is supported by data from laboratory simulation and experiments.

The flight conditions had no effect on the dynamics of spore formation among the Chlorella cells, the average number of autospores, formed by division of mother cells (Table 7) or the percentage of cells which divided into abnormal numbers of autospores (3, 5, 6, 7, etc, instead of 4, 8, 16). However, the plants aboard the flight showed a tendency toward an increase in the number of nonequivalent sporulations (autospores from one maternal cell of different size and different fate). Thus, in the flight experiment their number was 5.75 ± ± 1.23%, while it was 3.15 ± 0.81% in the control. The data in Table 8 indicate that in the flight version the Chlorella cells showed a statistically reliable increase in the frequency of mutant colonies.

In the experiment with onion seeds, the level of mutation was studied (the percentage of anaphases with aberrations) in the first mitosis of sprouts after 66-72 hours following moistening (4-5 mm-long sprouts); mitotic activity, sprouting energy on the third day, as well as germination of seeds on the 10th day following the start of sprouting.

TABLE 7. VIABILITY (IN %) AND AVERAGE NUMBER OF AUTOSPORES IN EXPERIMENTAL AND CONTROL CULTURES OF THE LARG-I STRAIN.

	Cultivation in light for 139-140 hours				Average number of autospores	
	Loss					
	Small, non-spore-forming cells	Cells, large and with autospores	After 1st sporulation	After 2nd sporulation	Survival	After 29-30 hours of cultivation in light
Control						
1	18.8	0.6	0.4	--	80.2	8.1
2	21.8	0.5	0.4	0.2	77.1	8.0
Experiment						
1	65.6	1.6	0.6	0.2	32.0	8.0
2	57.9	0.4	0.2	0.3	41.2	8.1

TABLE 8. NUMBER OF MUTATIONS IN EXPERIMENTAL AND CONTROL MATERIAL (IN %)

		Number of Counted Colonies	Total Percentage of Mutations
Control	1	6,704	0.48 ± 0.1
	2	8,639	0.41 ± 0.1
Experiment	1	3,148	1.28 ± 0.17
	2	3,829	1.19 ± 0.17

The difference in the level of mutation which was observed between the controls and between the experimental and transported controls turned out to be statistically unreliable. The difference between the experimental and laboratory controls was statistically reliable (Table 9). However, on the basis of the data which were obtained, it was not possible to decide whether the increase in the level of mutation, mitotic activity and germination energy that was observed in the experiment was a result of the influence of the space flight or whether it was caused by variations in the conditions of the medium which had nothing to do with the flight.

An experiment with barley seeds used material consisting of several varieties in various physiological states.

1. Moscow winter barley seeds in a state of organic rest.

2. Seeds of the same type of barley in a state of forced rest.

3. Moscow 121 barley seeds of five different reproductions; Moscow, Estonia, Pamir, Leninakanovsk, Tartu.

The Moscow winter barley seeds (organic rest) consisted of two batches; one batch was irradiated with a dose of 15 krad (620 r/m), the second was not irradiated.

The Moscow winter seeds in a state of forced rest were represented by two mixed reproductions (1966 and 1967). The seeds of the 1967 reproductions were stored without being irradiated at room temperature for 2 years. The seeds of the 1966 reproductions consisted of two batches; one batch was irradiated on 12 September 1966 with Co_{60} (15 krad, 500 r per minute) and stored for two years at room temperature; the second was stored under the same conditions but the seeds were not irradiated.

The nonirradiated seeds of the Moscow 121 barley from five ecologically different reproductions, which were in a state of forced rest, were divided into two parts upon return to Earth, one of which was irradiated with 10 krad (610 r per minute).

Germination was tested on the seeds of the MOS-121 barley from the 1968 crop, treated with ethylenamine, and on the untreated seeds as well as seeds which had been treated with mutagen after the flight; these tests were conducted immediately after the return to Earth and a month later. It was noticed that storage tended to restore their ability to germinate.

The experiment with turtles used the CT-I unit (container for turtles, number 1). The latter consists of an aluminum box with holders and a top made of plastic, fitted with a catch.

CT-I was not connected to the electrical and telemetry systems of the satellite. The general outline for performing the experiment consisted in recording by various methods the changes which developed in the biological objects after the CT-I was delivered to the laboratory. The CT-I contained three pond turtles (*Emys orbicularis*) weighing 250 grams, 4-5 years old. /62

On the fifth day, all of the experimental and control turtles were sacrificed simultaneously by decapitation and subjected to pathomorphological, hematological and cytological studies. Pieces of the animals' liver were mounted in one block using the Petrukhin method. Common sections were prepared from the blocks in a cryostat and stained according to Brasch. For other cytological studies, the spleen and the portion of the intestine were fixed in Carnoit fluid. The study of the sections did not reveal any significant structural differences or differences in the concentration of RNA in the cells. Preliminary analysis of the data from the hematological study indicates that the experimental turtles showed changes in the white blood cells. These changes took the form of a decrease in the total number of leucocytes in the peripheral blood. The results of the blood analyses are shown in Table 10.

The CT-I also contained lysogenic bacteria (*E coli*, K-12λ)

(a) in an aqueous solution,

(b) with the radioprotective preparation "Fin",

(c) with histamine

(d) with aminoethylisothiuronium,

(e) with serotonin.

TABLE 9. CYTOMORPHOLOGICAL ANALYSIS OF ONION SPROUTS

	Total no. of sprouts	Anaphase				Aberrations		Mitotic activity (index)	Germination energy (3 days)
		Normal	With aberrations	Total	%	Total	In 100 kl		
Control	162	4,005	127	4,132	3.4 0.3	141	3.4	5.5	45.5
Transported									
Control	18	1,009	44	1,053	4.0 0.6	48	4.6	9.3	--
Experiment	32	1,088	65	1,153	5.6 0.7	68	5.9	8.2	55.7

TABLE 10. CHANGE IN THE BLOOD IN EXPERIMENTS IN TURTLES.

Group	No. of animals	Erythrocytes (thousands)	Leucocytes in mm^3	Hb (in g %)
1	2	3	4	5
Experiment	1	520	420	7.6
	2	700	430	8.4
	3	480	480	7.6
Averages		566	443	7.87
Control	1	440	640	6.0
	2	600	600	8.4
	3	540	610	7.0
Averages		526	617	7.13
Control (vivarium)	1	530	720	7.6
	2	510	710	9.2
Averages		520	715	8.1

In the experiment with *E coli* K-12λ, which were in solution with radioprotectors and without them, the degree of induction of bacteriophages was determined on the basis of the infectiousness of the liberated phage particles. It was found that in the culture without radioprotectors the level of induced phagoproduction in laboratory experiments was observed under the influence of gamma rays from CO_{60} in a dose of 0.8 rad and a dose rate of 4 rad per day. In all cultures with radioprotectors, there was no increase in phage production.

CHAPTER IV.
RESULTS OF PRE- AND POST-EXAMINATIONS /64

1. Sensations and General Conditions of Cosmonauts

The crew members of the "Soyuz-3" - "Soyuz-8" spacecraft, as a rule, did not complain of any painful sensations or unpleasant feelings after their flights. They were only disturbed by fatigue related to the extensive program of work during the flight and on the day of landing.

After the "Soyuz-9" flight, cosmonauts A. G. Nikolayev and V. I. Sevast'yanov reported that their heads, hands, legs and even internal organs felt unusually heavy. The cosmonauts felt their weight. During the first hours after the flight, it was difficult for them to maintain a vertical posture, and they preferred to lie down. Movement in the vertical position was accompanied by unpleasant sensations (dizziness and weakness) these sensations bothered the cosmonauts for 2 to 3 days, but their severity gradually decreased. A characteristic feature was the fact that even in the "lying" position they felt "pressed down" into the bed.

Several days after landing, they still walked uncertainly. It took considerable effort to maintain a vertical posture. Thus, when going down the steps of an aircraft, they moved slowly, holding onto the handrails, placing their legs wide apart. However, regardless of this fact, they were able to climb up stairs under their own power to the fourth floor. The cosmonauts looked haggard, pale, and exhausted. They complained of a general weakness, pains in the muscles of the legs and back. The pains in the muscles became worse 2 to 5 days after the flight period. Both cosmonauts had improved appetites.

2. Studies of Hemodynamics Under Conditions of Basal Metabolism /65

All of the studies of hemodynamics involving members of the "Soyuz" spacecraft crews were performed early in the morning on an empty stomach under conditions that were used to determine basal metabolism. The gas energy exchange was determined by the method of Douglas and Holden while the minute volume of the circulation (MVC) was determined by the method of return breathing of CO_2 (the indirect method of Fick).

The procedure for determining the MVC was as follows. After the gas had been collected in a Douglas bag, the subject (after normal expiration) performed reverse breathing into and out of the bag for about 15-18 seconds. The content of CO_2 in the expired mixture was then recorded by an infrared gas analyzer using CO_2.

Calculation of the MVC was performed using the Fick formula. To do this, the content of CO_2 in the alveolar gas was equated to that in the arterial blood and the content of CO_2 in the mixed venous blood was determined by the exponential method of Defares. The values for gas exchange that were obtained were placed in the numerator.

After studying gas exchange on the second day after the end of five-day flights, the cardiac output increased primarily due to the pulse frequency, while the stroke volume of the heart remained practically constant. In studies made on the fourth day, there was a definite tendency toward a return of the hemodynamic values to the original level, but their complete normalization was not observed (Table 11).

The changes in hemodynamics in cosmonauts Sevast'yanov and Nikolayev on the second and third days after the end of the 18-day flight were different: during this period of time, the MVC of Sevast'yanov increased by 24.5 and 12.5%, respectively, exclusively at the expense of the stroke volume of the heart, while in Nikolayev it decreased by 8.8 and 17.9%, also primarily at the expense of the stroke volume. On the eighth day these tendencies ceased.

These changes in the hemodynamics of the crew members of the "Soyuz" space- /67
craft are apparently an ordinary "escape reaction" following the flight and have been described often on earlier occasions both on longer flights and during the period of recovery following the end of experiments in simulation of certain flight factors on Earth.

3. Study of Pulmonary Ventilation, Gas Exchange and Hemodynamics During Work on the Bicycle Ergometer

The study of the response reaction of the cardio-respiratory system to measured and submaximum physical work was performed only on the members of the

"Soyuz-4"-"Soyuz-8" spacecraft, who made flights lasting from 2 to 5 days. The preflight examination of the cosmonauts who flew aboard the "Soyuz-3"-"Soyuz-4" (2 and 3-day flights), was performed 18 to 20 days prior to the launch, while those for "Soyuz-5"-"Soyuz-7" were made about a month earlier.

Postflight examination of the crew members of these craft were performed about a day after landing (on the next day, after dinner), with the exception of the cosmonauts who flew aboard the "Soyuz-7", who were examined about two days later.

One after the other, with a fifteen minute interval, the cosmonauts carried out two tests:

--with measured physical work (600 kg/minute for 7 minutes);

--with gradually increasing physical work (600, 800, 1,000, 1,200 and 1,400 kg/minute, 1 minute each).

The results of the studies of gas exchange, pulmonary ventilation, pulse rate and several other hemodynamic parameters are represented in Tables 12 and 13.

After flights lasting two or three days aboard the "Soyuz-4" and "Soyuz-5" spacecraft, there were no severe or indicative changes in the majority of recorded parameters. After the 5-day flights, all of the cosmonauts showed an increase in pulse rate while a majority showed a decrease in the oxygen pulse in both types of work, but in the stable condition of measured work there was a slight increase in the oxygen consumption. Changes in the minute volume of respiration were diverse, although their average values after the flight were greater than those before the flight.

Hence, after the 5-day flight, a tendency was noted toward a deterioration /71 of the reaction of the cardiovascular and respiratory systems of the cosmonauts to physical work of average and submaximum intensity, i.e., a tendency toward a decrease in their physical working ability.

TABLE 11. SEVERAL HEMODYNAMIC PARAMETERS UNDER CONDITIONS OF BASAL METABOLISM IN THE MEMBERS OF THE CREWS OF THE "SOYUZ" SPACECRAFT BEFORE THE BEGINNING (B) AND AFTER THE END (A) OF THE FLIGHT PERIOD.

Cosmonaut	Duration of flight (days)	Observation time (days after flight)	Parameters								
			MVC			SV			FCC		
			B	A	%	B	A	%	B	A	%
G. Shonin			4.06	4.83	±19.0	81.2	80.5	-1.0	50	60	+20.0
V. Kubasov	5	2	3.99	4.09	+ 2.5	70.0	62.5	-10.7	57	64	+12.3
A. Filipchenko			4.22	5.71	+35.3	85.0	84.0	-1.2	50	68	+36.0
V. Gorbatko			4.61	4.72	+ 2.4	74.4	73.7	-0.5	62	64	+ 3.2
V. Volkov			3.82	4.44	+16.2	68.2	74.0	+8.5	56	60	+ 7.1
G. Shonin			4.06	4.84	+19.2	81.2	80.7	-1.0	50	60	+20.0
V. Kubasov			3.99	3.93	-1.5	70.0	70.4	+0.6	57	56	-1.8
A. Filipchenko	5	4	4.22	5.93	+40.5	85.0	95.5	+11.7	50	62	+24.0
V. Gorbatko			4.61	4.66	+1.1	74.4	67.0	-9.9	62	70	+12.9
V. Volkov			3.82	4.70	+23.0	68.2	78.5	+15.1	56	60	+7.1
V. Sevast'yanov	18	2	4.40	5.48	+24.5	70.8	88.4	+24.9	62	62	--
G. Nikolayev			4.87	4.44	-8.8	76.1	69.3	-8.9	64	64	--
V. Sevast'yanov	18	3	4.40	4.95	+12.5	70.8	82.5	+16.6	62	60	-3.2
G. Nikolayev			4.87	4.00	-17.9	76.1	61.5	-19.2	64	68	+6.3
V. Sevast'yanov	18	8	4.40	5.26	+19.5	70.8	79.7	+12.6	62	66	+6.5
G. Nikolayev			4.87	4.45	-8.6	76.1	66.4	-12.7	64	67	+4.7

Legend: MVC = Minute Volume of Circulation SV = Stroke Volume of the Heart
VCC = Frequency of Cardiac Contraction

TABLE 12. SEVERAL PARAMETERS OF GAS EXCHANGE AND HEMODYNAMICS IN THE "STABLE STATE" (8 MINUTES) OF MEASURED PHYSICAL WORK (600 kg PER MINUTE) ON A BICYCLE ERGOMETER, PERFORMED BEFORE (B) AND AFTER (A) THE FLIGHTS.

Cosmonauts	Duration of flight	Parameters											
		Consumption of CO_2 (mm/min)			Pulse rate (beats per min)			Oxygen pulse (mm per stroke)			Minute volume of respiration		
		B	A	%	B	A	%	B	A	%	B	A	%
A. S. Yeliseyev	2	1,567	1,621	+3.4	113	123	+8.8	13.9	13.2	-5.0	34	33	-2.9
Ye. V. Khrunov		1,567	1,617	+3.2	113	110	-2.7	13.9	14.7	+5.8	27	32	+18.5
V. A. Shatalov	3	1,501	1,562	+4.1	126	130	+3.2	11.9	12.0	+0.8	31	31	---
V. V. Volynov		1,458	1,464	+0.4	103	102	-1.0	14.2	14.4	+1.4	39	38	-2.6
G. S. Shonin	5	1,450	1,532	+5.7	108	125	+15.7	13.4	12.3	+8.2	29	35	+20.7
V. N. Kubasov		1,452	1,460	+0.6	109	112	+2.8	13.3	13.0	-2.3	37	41	+10.8
A. V. Filipchenko		1,396	1,388	-0.6	108	117	+8.3	12.9	11.9	-7.8	36	34	-5.6
V. V. Gorbatko		1,294	1,399	+8.1	118	128	+8.5	11.0	11.0	--	29	31	+6.9
V. A. Shatalov		1,496	1,532	+2.4	113	129	+14.2	13.2	11.9	-9.8	34	40	+17.6
A. S. Yeliseyev		1,384	1,442	+4.2	108	117	+8.3	14.2	12.3	-13.4	33	34	+3.0

TABLE 13. SOME PARAMETERS OF GAS EXCHANGE AND HEMODYNAMICS UNDER LOADS ON A BICYCLE ERGOMETER, 1,400 kg PER MINUTE BEFORE (B) AND AFTER (A) THE END OF SPACEFLIGHTS

Cosmonauts	Duration of flight	Parameters											
		Consumption of CO_2 (mm/min)			Pulse rate (beats per min)			Oxygen pulse (mm per stroke)			Minute volume of respiration		
		B	A	%	B	A	%	B	A	%	B	A	%
A. S. Yeliseyev	2	2,578	2,535	-1.7	157	162	+3.2	16.4	15.6	-4.9	62	63	+1.6
E. V. Khrunov		2,804	2,783	-0.7	152	153	+0.7	18.4	18.2	-1.1	60	72	+20
V. A. Shatalov	3	2,552	2,480	-2.8	170	177	+4.1	15.0	14.0	-6.7	68	61	-10.
B. V. Volynov		2,321	2,279	-1.8	149	147	-1.3	15.6	15.5	-0.6	71	74	+4.2
G. S. Shonin	5	2,222	2,172	-2.3	144	164	+13.9	15.4	13.2	-14.3	46	53	+15.
V. N. Kubasov		2,072	2,255	+8.8	142	147	+3.5	14.6	15.3	+4.8	51	62	+21.
A. V. Filipchenko	5	2,116	2,188	+3.5	145	155	+6.9	14.6	14.1	-3.4	60	52	-13.
V. V. Gorbatko		2,079	2,303	+10.8	160	167	+4.3	13.0	13.8	+6.2	52	57	+9.6
V. N. Volkov		2,352	2,247	-4.5	159	161	+1.2	14.8	14.0	-5.9	54	63	+16.
V. A. Shatalov	5	2,300	2,350	+2.2	152	164	+7.9	15.1	14.3	-5.3	62	65	+4.8
A. S. Yeliseyev		2,217	2,181	-1.6	140	150	+7.1	15.8	14.5	-8.2	57	54	-5.3

4. Study of Pulmonary Ventilation, Gas Exchange and Hemodynamics During Orthostatic Tests

Examination of the crew members of the "Soyuz-3"-"Soyuz-9" spacecraft took place approximately 3-4 weeks prior to the start of the spaceflight, during the morning hours. /72

Postflight examinations, as a rule, were performed 24 hours after the end of the flight (the only exception was for cosmonauts V. A. Shatalov and A. S. Yeliseyev, who were examined during the evening hours approximately 30-32 hours after landing, as well as cosmonauts V. I. Sevast'yanov and A. G. Nikolayev, who were examined on the 2nd and 3rd days, respectively). In addition, they were examined on the 6th and 11th days after the end of the flight aboard the "Soyuz-9" spacecraft.

A passive orthostatic test with 10-minute tilting of a rotating chair to a vertical position (88°) was performed after the subject had been resting in a supine position for at least 20 minutes. In the 11th minute of the test, reverse breathing was performed to calculate the minute volume of blood circulation (only the members of the crews "Soyuz-6"-"Soyuz-9" spacecraft).

The results of the studies showed that while there were no noticeable changes in the recorded parameters of any kind 24 hours after 2-day flights, after 3- to 5-day flights all the cosmonauts showed an increase in pulse rate in the vertical position to a greater or lesser degree, a majority of them showed a decrease in the oxygen pulse and beginning with the 4-day flight there was an increase in pulmonary ventilation (Table 14). The stroke volume of the heart in the vertical [Note: text missing] by 2-6%, in /75
cosmonaut V. I. Sevast'yanov, who was examined two days after landing -- by 10%, and in A. G. Nikolayev after five days by 27%.

Regardless of the fact that the passive orthostatic test was given to Sevast'yanov about 2 days after the landing, the orthostatic stability of this cosmonaut was sharply reduced and regardless of the completely adequate level of the stroke volume of his heart, residual signs indicated an extreme load on the mechanisms responsible for maintaining sufficient circulation in the vertical posture.

TABLE 14. SEVERAL PARAMETERS OF THE CARDIO-RESPIRATORY SYSTEM OF THE CREW MEMBERS OF THE "SOYUZ" SPACECRAFT IN THE VERTICAL POSITION DURING PASSIVE ORTHOSTATIC TESTS PERFORMED BEFORE (B) AND AFTER (A) FLIGHTS.

Cosmonaut	Duration of flight	Time of examination *(days after flight)	Parameters								
			Pulse frequency (beats/min)			Oxygen pulse (ml/beat)			Minute volume (ml)		
			B	A	%	B	A	%	B	A	%
Yeliseyev	2	1	78.6	82.1	+4.5	4.18	3.75	-10.3	12.0	12.3	+2.5
Khrunov		1	81.6	77.0	-5.6	2.98	3.27	+9.3	7.7	7.8	+1.3
Shakalov	3	1	76.0	89.0	+17.1	4.01	3.54	-11.9	10.9	9.0	-17.4
Volynov		1	59.1	66.0	+11.7	4.37	4.27	-2.3	9.8	9.0	-3.2
Beregovoy	4	1	72.0	97.0	+34.7	3.51	2.95	-16.2	10.8	11.9	+10.2
Shonin		1	61.4	91.9	+49.7	4.20	3.20	-23.9	8.3	9.8	+18.1
Kubasov		1	76.0	82.9	+9.1	2.97	3.38	+14.0	10.9	11.9	+9.2
Filipchenko		1	71.2	95.3	+33.8	3.77	3.21	-14.8	9.9	10.8	+9.1
Gorbatko	5	1	72.6	99.7	+37.3	2.99	2.40	-19.8	7.1	8.6	+21.1
Shatalov		1.5	75.6	87.7	+16.0	3.36	2.95	-19.4	8.8	10.2	+15.9
Yeliseyev		1.5	64.9	78.6	+21.1	3.45	3.50	+1.4	9.4	9.7	+3.2
Sevast'yanov		2	94.0	110.7	+17.8	2.83	2.78	-1.8	11.4	29.3	+157.0
Nikolayev		3	98.0	102.0	+4.1	2.48	2.45	-1.2	8.9	7.7	-13.5
Sevast'yanov	18	6	94.0	104.5	+11.1	2.88	2.44	-13.8	11.4	11.3	-0.9
Nikolayev		6	98.0	116.0	+18.4	2.48	2.09	-15.8	8.9	6.5	-27.0
Sevast'yanov		11	94.0	93.0	-1.1	2.88	2.90	+2.5	11.4	10.1	-11.4
Nikolayev		11	98.0	96.2	-1.8	2.48	2.28	-8.1	8.9	8.0	-10.1

TABLE 14. CONCLUDED

Cosmonauts	Parameters								
	% CO_2 (percentile content of CO_2 in alveolar gas)			Stroke volume of the heart (ml)			Minute volume of circulation (liters)		
	B	A	%	B	A	%	B	A	%
Yeliseyev	5.5	4.7	-14.5						
Khrunov	6.8	5.5	-19.1						
Shakalov	4.8	5.0	+4.2						
Volynov	4.4	4.6	+4.5						
Beregovoy	4.2	4.5	+7.1						
Skovin	4.6	4.7	+2.2	61.0	41.0	-32.8	3.8	3.7	-2.7
Kubasov	3.3	4.4	+33.3	48.0	47.0	-2.1	3.6	3.9	+8.3
Filipchenko	4.7	4.9	+4.3	58.0	57.0	-1.7	4.1	5.5	+34.1
Gorbatko	5.2	4.9	-5.8	52.0	36.0	-30.8	3.9	3.6	-7.7
Shatalov	4.6	4.7	+2.2	54.0	51.0	-5.6	4.2	4.5	+7.1
Yeliseyev	4.8	4.8	0	49.0	48.0	-2.0	3.2	3.9	+21.9
Sevast'yanov	4.3	2.2	-48.8	52.9	47.5	-10.0	4.92	5.92	+20.3
Nikolayev	4.9	4.8	-2.0	47.4	50.9	+7.4	4.60	5.26	+14.3
Sevast'yanov	4.3	4.4	+2.3	52.9	54.2	+2.5	4.92	5.53	+12.4
Nikolayev	4.9	4.9	0	47.4	34.4	-27.4	4.60	4.02	-12.6
Sevast'yanov	4.3	4.2	-2.3	52.9	53.6	+1.3	4.92	4.98	+1.6
Nikolayev	4.9	5.1	+4.1						

Note: The minimum values per test are given for percentage of CO_2 and the maximum values are given for minute respiration volume. Stroke volume and minute volume of circulation were determined by the indirect method of Fick (reverse breathing during the 11th minute of a stay in the vertical posture).

These data, in conjunction with the results of passive orthostatic tests, indicate a considerable decrease in the postural resistance of cosmonauts who performed an 18-day flight. From this we can conclude that the performance of longer flights will require careful use of means intended to prevent and treat postflight orthostatic instability.

5. State of Regulation of the Vertical Position /76

In space medicine, the problem of regulation of the vertical position occupies a particularly important place. Since the most of the activity of a human being is carried out in the vertical position, any change in the regulation of the ability to stand upright may have the effect of reducing the working ability. There are certain data available on the possibility of deterioration of a number of functions in a vertical position after a stay under conditions of weightlessness.

To study the statics, we used a method called stabilography, which reflects the movements of a common center of gravity (CCG) of a body in the sagittal and frontal planes. The duration of the test was 10 minutes. The subject was placed on a stabiloplatform in a strictly determined position: blocks were always placed so that the distance between the feet was 2 cm and the toes were turned out in an angle of 45°. If the eyes were open and the head pointed straight ahead, the position was called "initial." Before each study and after its completion, the apparatus was calibrated with a special weight. The average frequency and amplitude were taken into account in the analysis of the stabilograms.

Prior to the spaceflight, all of the cosmonauts failed to show any deviations from the norm.

In the examination conducted up to 2 days after the flight, the cosmonauts complained of pains in the muscles of their legs, sensations of "heaviness of the entire organism," a considerable increase in weight of all objects and they also noticed that it was difficult for them to maintain their equilibrium when they stood up. This was especially true in the case of the crew members of the "Soyuz-9" spacecraft.

TABLE 15. STABILOGRAPHIC INDICATIONS OF CHANGES IN THE COMMON CENTER OF GRAVITY IN THE CREW MEMBERS OF THE "SOYUZ-3"-"SOYUZ-9" SPACECRAFT (AMPLITUDES OF VIBRATIONS IN mm).

Cosmonauts	Sagittal Plane						Frontal Plane					
	Eyes open, Before	After	Eyes closed, Before	After	Eyes open, Before	After	Eyes open, Before	After	Eyes closed, Before	After	Eyes open, Before	After
G. T. Beregovoy	11.8	14.0	14.2	16.2	12.8	14.0	11.8	12.6	12.0	10.6	6.4	11.8
V. A. Shatalov	13.2	13.2	16.2	15.2	12.8	14.0	10.0	10.8	10.4	14.0	11.6	14.8
B. V. Volynov	15.8	24.0	15.8	17.6	16.2	15.2	16.0	35.0	15.8	19.6	16.6	18.0
E. V. Khrunov	11.2	12.0	13.4	10.8	8.6	8.8	8.6	11.8	7.9	9.8	8.4	9.4
A. S. Yeliseyev	13.8	13.2	15.6	16.8	11.2	14.0	10.6	11.8	12.2	14.8	13.4	15.2
G. S. Shonin	16.0	16.2	15.0	14.8	15.2	18.2	15.4	15.8	11.4	15.2	12.2	14.4
V. I. Kubasov	13.0	13.0	12.2	12.6	12.0	12.4	14.6	11.6	11.0	7.2	12.2	7.4
A. S. Filipchenko	13.2	21.8	14.8	21.8	8.6	23.2	9.0	16.4	9.2	14.4	7.4	15.8
V. I. Volkov	10.4	15.6	13.4	20.0	11.0	14.6	8.4	14.4	11.2	15.2	9.4	14.4
V. V. Gorbatko	13.8	16.2	16.4	19.0	14.4	17.8	10.8	11.4	11.8	13.8	10.4	12.6
V. A. Shatalov	14.6	17.0	21.6	23.0	14.0	20.6	13.2	13.6	13.8	18.0	13.2	17.4
A. S. Yeliseyev	15.6	18.2	17.2	19.8	12.8	19.0	11.2	12.0	11.0	14.6	10.8	12.0
Average	13.5	16.2	15.5	17.3	12.5	15.9	11.6	14.8	11.1	13.8	11.0	13.6
A. G. Nikolayev	21.9	26.8	26.1	31.0	23.2	26.9	23.6	29.2	22.4	23.2	18.8	23.8
V. I. Sevast'yanov	20.4	27.9	28.1	33.7	22.0	29.6	19.1	26.3	22.2	26.9	20.6	26.1
Average	21.1	27.3	27.1	32.3	22.6	28.2	21.3	27.8	22.3	25.0	29.2	24.9

TABLE 16. STABILOGRAPHIC FIGURES FOR VIBRATIONS OF A COMMON CENTER OF GRAVITY AMONG THE CREW MEMBERS OF THE "SOYUZ-3"-"SOYUZ-9" SPACECRAFT (FREQUENCY OF VIBRATIONS).

Cosmonauts	Sagittal Plane						Frontal Plane					
	Eyes open,		Eyes closed,		Eyes open,		Eyes open,		Eyes closed,		Eyes open,	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
G. T. Beregovoy	45	42	56	49	39	49	25	25	29	41	18	34
V. A. Shatalov	49	51	59	62	59	49	44	44	53	50	49	39
B. V. Volynov	39	40	60	44	37	36	48	43	54	54	35	42
E. V. Khrunov	39	46	55	50	63	53	31	31	45	32	29	25
A. S. Yeliseyev	56	35	62	38	42	41	63	55	61	55	53	58
G. S. Shonin	45	45	74	69	35	24	50	33	51	53	28	31
V. I. Kubasov	27	34	28	34	28	37	18	19	18	22	14	11
A. S. Filipchenko	47	35	54	51	38	34	44	32	52	39	29	34
V. I. Volkov	34	29	27	29	31	30	32	30	29	40	27	29
V. V. Gorbatko	34	37	57	44	53	29	31	38	49	31	38	22
V. A. Shatalov	51	56	64	80	56	55	60	41	57	54	47	32
A. S. Yeliseyev	46	34	65	72	51	57	42	36	66	53	44	32
Average	42.5	40	55	52.5	44	41	41	35.5	47	44	34	32.5
A. G. Nikolayev		53	57	64	45	41	58	27	55	46	49	29
V. I. Sevast'yanov		62	65	57	71	52	66	46	70	54	57	45
Average		57	61	61	58	46	62	36	62	50	53	37

The stabilographic study revealed a decrease in the vertical stability of the cosmonauts (Tables 15, 16). Almost all the cosmonauts, both in the initial pose and with eyes closed, showed an increase in the amplitude of the oscillations and the frequency of the oscillations of the CCG decreased. Similar relationships between the frequency and amplitude usually indicate instability of the vertical position of the body in man. These changes were also particularly marked among the crew members of the "Soyuz-9" spacecraft (Tables 15, 16). It was noticed that in contrast to the previous flights of the "Soyuz" spacecraft, the members of the "Soyuz-9" crew showed normalization of the regulation of the vertical position only on the tenth day after the flight. /77

One of the reasons for the disturbances that were noted in the regulation of the vertical position may be the decrease in muscle tone, frequently observed after the end of spaceflight and experiments simulating individual effects of weightlessness. After completing the flight aboard the "Soyuz-9" spacecraft, a decrease in muscle tone of this kind was observed.

Another reason for deterioration of regulation of the vertical position apparently is the change in the interaction of analyzers. This is indicated by the increase in the indices of variation of the CCG with the eyes closed. As a result of changes in afferentation from all mechanoreceptors a functional system involving operation of the analyzers takes place in a state of weightlessness. The return to the gravitational field of the Earth causes a second adjustment of the activity of many analyzer systems. The possible reason for the defects in statics which developed may be disruption of the interaction of various muscle groups, i.e., disturbance of synergy which is aimed at the maintenance of a vertical position [Note: text missing]. ...confined to bed rest (V. S. Gurfinkel', V. I. Pal'sev, 1969). A further stay under terrestrial conditions leads to adaptation of the organism to the action of the force of gravity, as indicated by the results obtained on the 10th day of examination. /80

Hence, readaptation to conditions of terrestrial gravitation has a phasal nature, as we can see from the indicators of stability during maintenance of a standing posture. By way of orientation, we might suggest three phases. The first consists in a reduction of the frequency and magnitude of the amplitude of the oscillations of the CCG. This is obviously caused by a change in the total afferentation caused by a change from a stay in a prolonged state of weightlessness to terrestrial gravitation and the formation of a previous stereotype. The second phase consists in an increase in all of the stabilographic indices, which may possibly be caused by an increase in the proprioceptive impulsation and a gradual restoration of muscle tone. However, the accuracy of carrying out the individual motor adjustments is still disturbed. The third and final phase of readaptation is further restoration of the condition of homeostasis, as well as accurate coordination of complex motor acts.

6. Condition of the Neuromuscular Apparatus

Studies were performed 18-30 days prior to the flight and on the second day following the landing. In the case of the cosmonauts who had made the 18-day spaceflight, the dynamics of restoration of these parameters was followed during the month that came after the landing. /81

The muscle tone was studied by methods of sclerometry (according to Sirmai), making it possible to determine changes in the strength of the muscles, indirectly characterizing the condition of the muscle tone.

The strength of the muscles was determined by means of standing and manual dynamometers.

The perimeters of the shin, hip and shoulder were measured with a metal tape for strict determination of their tangent.

Studies conducted after the comparatively short (up to 5 days) flights of the "Soyuz-3"--"Soyuz-8" spacecraft indicated that a period of this length of exposure to the effects of spaceflight factors has no serious consequences as far as the neuromuscular system is concerned. At the same time, an analysis of the results that were obtained made it possible to reveal certain features in connection with the development of changes that are expressed in a decrease of strength on the stand and muscle tone of the lower extremities. The tone and force of the muscles of the upper extremities changed insignificantly (Tables 17, 18). In measuring the perimeters of the extremities, no significant reduction was observed in them, which may indicate the existence of muscle atrophy (Table 19).

TABLE 17. VALUES OF CHANGE IN MUSCLE TONE IN COSMONAUTS AFTER FLIGHTS (IN % OF PREFLIGHT DATA).

Duration of flight	Spacecraft	No. of subjects	Period of examination (days after landing)	Muscle Investigated		
				Anterior tibial	Quadriceps, hip	Biceps, arm
Up to 5 days	"Soyuz-3" "Soyuz-8"	12	2	-7.5	-10.4	-5.4
18 days	"Soyuz-9"	2	2	-11.2	-13.4	+5.5
			4	- 8.2	-12.7	--
			7	- 4.4	- 7.6	+2.0
			11	- 1.5	- 9.8	+3.4
			36	± 0	- 5.2	+3.5

TABLE 18. VALUES OF CHANGES IN STRENGTH INDICATORS IN COSMONAUTS FOLLOWING FLIGHTS (IN % OF PREFLIGHT DATA).

Duration of flight	Spacecraft	Number of subjects	Period of investigation (days after landing)	Standing strength	Strength of wrists	
					Left	Right
Up to 5 days	"Soyuz-4"	3	2	-24.5	+2.6	±0
	"Soyuz-5"	1	2	- 3.1	±0	-2.7
	"Soyuz-6"	2	2	-28.6	-3.2	-4.0
	"Soyuz-7"	3	2	-11.1	+2.5	-6.0
	"Soyuz-8"	2	2	-17.6	+6.5	+5.1
18 days	"Soyuz-9"	2	2	-29.9	+5.7	-6.1

TABLE 19. AVERAGE VALUES OF CHANGES IN PERIMETERS OF EXTREMITIES (IN mm) IN ASTRONAUTS AFTER FLIGHT (IN % OF PREFLIGHT DATA).

Duration of flight	Spacecraft	No. of subjects	Periods of examination (days after landing)	Shin	Hip	Shoulder
Up to 5 days	"Soyuz-3" "Soyuz-8"	12	2	-2.0	-7.0	-5.0
18 days	"Soyuz-9"	2	2	-12.0	-27.0	-2.0
			4	- 9.0	-22.0	--
			7	- 6.0	-21.0	-2.0
			11	±0	-15.0	±0
			36	±0	±0	+7.0

A comparative evaluation of the postflight results of the investigation indicate that a lengthening of this period of time spent under conditions of spaceflight for up to 18 days leads to a more severe change as far as the support-muscular system in man is concerned.

This is revealed by a significant decrease in the tone and strength of the gravitational muscles, a reduction in the perimeters of the lower extremities, a lengthening of the periods of recovery of these indicators to the original level.

7. Study of Mineral Saturation of Bone Tissue /85

An evaluation of the mineral saturation of bone tissue was carried out by means of roentgenophotometry.

The following parts of the skeleton were studied:

--the central segment of the calcaneus;

--the bases in the principal phalanges of the wrist.

The original data were obtained one month before the flight.

The results of the postflight studies are shown in Table 20.

The results of roentgenophotometric studies of mineral saturation of bone tissue indicate:

1. The process of demineralization of bone tissue takes place during spaceflight.

2. The process occurs more rapidly and more severely in comparison with the same exposure under terrestrial simulation experiments.

3. Spaceflights lasting up to 18 days do not have any kind of influence on bone tissue that threatens the health of these cosmonauts or their safe return to Earth.

4. The process of demineralization is completely reversible within these limits when the cosmonauts return to ordinary terrestrial conditions of life.

As far as the problem of demineralization of the skeleton under conditions of weightlessness is concerned, without going into a discussion involving the mechanisms of this process, there is good reason to believe that one of the causative factors is the absence of adequate stress on the bone system that is usually applied by the weight of the body. /86

An analysis of the data obtained following a series of flights aboard the "Soyuz" spacecraft does not justify viewing these changes in the calcium balance and mineral saturation of the bone tissue as anything that threatens the individuals or is disastrous, but it is not definite that a stay in a condition of weightlessness on the order of three months or more would be equally safe in this regard.

TABLE 20. CHANGE IN OPTICAL DENSITY OF BONE TISSUE IN THE POSTFLIGHT PERIOD (IN % OF ORIGINAL LEVEL).

Area studied	"Soyuz-3"	Soyuz-9"			
	G. T. Beregovoy	A. G. Nikolayev		V. I. Sevast'yanov	
	4 days	2 days	22 days	2 days	22 days
Phalanges of the wrist:					
3d finger	-6.8	-5.0	-2.5	-5.0	-5.0
4th finger	-6.6	-3.1	0	-4.3	-1.4
5th finger	-9.9	-4.7	-1.6	-8.9	-4.4
Calcaneus	-7.7	-8.5	-4.5	-9.6	-3.4

8. Metabolism (Including Water-Salt Exchange) /87

In working out the program of biochemical studies aboard the "Soyuz" spacecraft, the researchers proceeded on the basis of the necessity to obtain data for predicting the ability of man to withstand flights lasting for periods on the order of a month. To do this, the results of appropriate studies aboard the "Vostok" and "Voskhod" spacecrafts were taken into account, as well as the results of experiments with hypokinesia.

During previous spaceflights, a decrease in the body weight of cosmonauts was observed as a result of dehydration and a slight increase in the content of urea in the blood. After the flights, the functioning of the osmoregulatory systems of the organism was disturbed, and retention of ingested water was observed together with instability of glycemia. In simulation experiments, there was a significant increase in the content of cholesterol in the blood, increasing the content of urea in the blood, while the sugar level in the blood was unstable. These experiments also demonstrated that with a correct organization of the total program and the diet it is possible to avoid negative nitrogen or in any case to reduce it to low values that are at the limit of sensitivity of the method, which cannot have any effect on the state of health if the individual is exposed to these conditions for one to two months.

An analysis of the possible disruption of the calcium balance and its influence on the strength of the bone showed that on flights lasting up to one month and possibly up to three months this problem is not significant. Therefore, no corresponding studies were performed and the excretion of calcium with the urine was studied in order to evaluate the ionoregulatory function of the kidneys.

The most important problem in the biochemical studies during the spaceflights was an evaluation of the state of nitrogen balance, since it makes it possible to have the most integral evaluation of the functional state of the organism, During the flights in the "Soyuz" program, which lasted 3-5 days, /88
the body weight of the cosmonauts decreased slightly (Table 21), but it rapidly recovered while the excretion of total nitrogen with the urine following the

end of the flight did not increase (Table 22, 23). This makes it possible to exclude increased tissue catabolism, explaining the loss of weight by dehydration exclusively. The retention of water and salts on the first day following landing supports such a theory. The absolute losses of fluid from the organism during the first few days in space were small and had nothing to do with the duration of the flight, so there is no reason to believe that they could have had a significant influence on the working ability of the cosmonauts or their ability to withstand the action of harmful flight factors.

On the 18-day flight and immediately after it was over the excretion of the total nitrogen product in the urine was generally within the physiologically normal limits (Tables 22, 23, 24). However, on the basis of these data, we still cannot conclude that there was no negative nitrogen balance, since with the considerable duration of the action the results of the studies on individual days may not be indicative. At the same time, however, the slow restoration of weight following the flight makes it possible to think that there was an increase in tissue catabolism and that it dominated the synthetic processes.

After the flights, there was disruption of osmoregulation which took the form of retention of water while carrying out tests with water loads and an increased excretion of calcium and sodium both at the level of diuresis while this test was being performed and also on the second day after landing (Table 25). It is interesting that while the ability to retain drinking was sharply pronounced even after the flights lasting several days, the inability to retain sodium and calcium was more marked after long flights. During the flights and immediately afterward, there was a slight increase in the content of urea in the blood, which apparently was also related to the adjustment of the kidney function.

In contrast to the situation in the simulation experiments, the content of cholesterol in the blood after the flights showed practically no increase (Table 6). These observations are important for an evaluation of the possibility of development and aggravation of the atherosclerotic process during a flight. /94

TABLE 21. DECREASE IN BODY WEIGHT AFTER SPACE FLIGHTS.

No.	Cosmonauts	Flight duration in days	Decrease in body weight, kg
1	G. T. Beregovoy	3 days 22 hrs 51 min	2.4
2	V. A. Shatalov	2 days 23 hrs 14 min	4.0
3	B. V. Volynov	3 days 46 min	2.4
4	A. S. Yeliseyev	1 day 23 hrs 39 min	2.0
5	Ye. V. Khrunov	1 day 23 hrs 39 min	2.0
6	G. S. Shonin	4 days 22 hrs 42 min	2.4
7	V. N. Kubasov	4 days 22 hrs 42 min	2.1
8	A. V. Filipchenko	4 days 22 hrs 41 min	3.9
9	V. V. Gorbatko	4 days 22 hrs 41 min	2.0
10	V. N. Volkov	4 days 22 hrs 41 min	2.4
11	V. A. Shatalov	4 days 22 hrs 41 min	2.2
12	A. S. Yeliseyev	4 days 22 hrs 41 min	3.6
13	A. G. Nikolayev	17 days 17 hrs	2.7
14	V. I. Sevast'yanov	17 days 17 hrs	4.0

TABLE 22. EXCRETION OF VARIOUS SUBSTANCES WITH THE URINE FOR COSMONAUTS DURING THE FIRST DAYS FOLLOWING LANDING.

Spacecraft		Duration, in hrs	Urine volume, ml	17- OH-KS mg	Vanillylamygadalic acid	Total nitrogen, g	Creatinine, g	Phosphorus, g	Chlorine, meq.	Sodium, meq.	Potassium, meq.	Calcium, meq.	Magnesium, meq.
"Soyuz-3"	G. T. Beregovoy	24	690	2.5	4.1	14.8	1.58	1.12	--	52	80	--	--
	V. A. Shatalov	24	---					0.67	64	117	35	9.0	--
"Soyuz-5"	B. V. Volynov	24	1,100	3.5	--]	18.2	1.86	0.97	164	200	62	10.6	--
	E. V. Khrunov	24	1,200	2.6	--	21.8	2.1	1.05	160	206	58	10.2	--
	A. S. Yeliseyev	24	1,110	4.07	--	20.4	2.26	1.09	96	165	51	11.6	--
"Soyuz-6"	G. S. Shonin	24	880	3.9	4.8	16.0	1.66	0.83	61	144	37	21.9	6.2
	V. N. Kubasov	23	705	4.2	4.2	14.5	1.47	1.0	67	116	35	17.8	8.0
"Soyuz-7"	A. V. Filipchenko	22	655	4.2	4.1	12.8	1.43	0.46	129	109	39	9.3	3.5
	V. N. Volkov	21.7	590	1.8	3.6	9.1	0.94	0.58	38	71	26	7.1	3.3
	V. V. Gorbatko	22.5	730	2.8	4.6	15.7	1.5	0.82	50	97	31	8.6	5.0
"Soyuz-8"	V. A. Shatalov	21	580	2.8	3.5	14.6	1.75	0.60	54	88	39	4.6	5.1
	A. S. Yeliseyev	21	875	3.4	5.2	15.6	1.62	0.90	34	102	42	11.1	4.1
"Soyuz-9"	A. G. Nikolayev	24	690	3.3	--	15.0	2.1	0.8	92	104	25	11.5	--
	V. I. Sevast'yanov	24	665	3.7	--	13.1	1.5	0.76	65	125	30	11.5	--

TABLE 23. EXCRETION OF VARIOUS SUBSTANCES WITH THE URINE IN COSMONAUTS DURING THE FIRST DAYS FOLLOWING LANDING

Spacecraft	Cosmonauts	Duration in hours	Urine volume in ml	17-OH-KC in mg	Vanillylamygadalic acid	Total nitrogen in g	Creatinine in g	Phosphorus in g	Chlorine in g	Sodium in g	Potassium in meq	Calcium in meq	Magnesium in meq
"Soyuz-3"	G. T. Beregovoy	24	600	2.5	4.6	13.2	1.43	0.54	-	32	33	-	-
"Soyuz-6"	G. S. Shonin	23	1,080	4.2	4.6	17.3	1.83	0.85	110	190	44	21.1	8.7
	V. N. Kubasov	23	1,220	5.4	5.1	18.3	2.07	0.88	229	325	78	32.1	13.0
"Soyuz-7	A. V. Filipchenko	23	885	4.8	5.4	14.0	1.73	0.63	94	158	44	13.0	7.2
	V. N. Volkov	22.7	830	4.3	3.6	11.7	1.30	0.42	125	171	35	15.2	10.1
	V. V. Gorbatko	22.5	830	5.1	3.8	13.9	1.64	0.46	135	149	42	13.2	7.9
"Soyuz-8"	V. A. Shatalov	23	780	2.9	5.1	14.7	2.0	0.59	128	184	45	9.7	7.6
	A. S. Yeliseyev	23	690	2.5	2.9	12.2	1.54	0.51	94	121	44	9.9	5.2
"Soyuz-9"	A. G. Nikolayev	24	2,000	4.30	-	15.6	2.0	1.15	96	91	15	18	-
	V. I. Sevast'yanov	24	1,430	5.4	-	16.9	2.1	1.0	135	224	42	15	-

Note: A. G. Nikolayev and V. I. Sevast'yanov were tested on the second day with a water load.

TABLE 24. EXCRETION OF VARIOUS SUBSTANCES WITH THE URINE BY CREW MEMBERS OF THE "SOYUZ-9" SPACECRAFT DURING THE 18-DAY FLIGHT (PER DAY)

	Volume in ml	Total nitrogen	Creatinine in g	17-OH-KC in mg	Phosphorus in g	Cl	Na	K	Ca
						in milligram-equivalents			
A. G. Nikolayev									
1 day	890	10.0	1.7	1.8	0.47	225	300	35	13
2 days	840	13.8	2.1	2.5	0.84	183	188	38	10
18 days	1,028	19.1	2.6	3.8	1.27	175	188	48	20
V. I. Sevast'yanov									
1 day	800	9.2	0.64	2.6	4.6	132	205	27	12
2 days	750	13.2	2.1	1.1	413	123	145	37	12
18 days	830	15.0	2.1	5.1	4.8	137	188	42	15

TABLE 25. SEVERAL PARAMETERS OF KIDNEY FUNCTION IN A TEST INVOLVING A WATER LOAD FOR COSMONAUTS FOLLOWING FLIGHTS

Spacecraft	Cosmonauts	Excretion of water in %: After 2 hrs	Excretion of water in %: After 4 hrs	Maximum minute diuresis ml/min	Concentration at max diuresis in mg/eq/liter	Excretion of sodium at max diuresis in ml/eq/min	Excretion in 2 hours: 17-OH-KC in mg	Excretion in 2 hours: Electrolytes in mg/eq: Na	K	Ca	Mg
"Voskhod-1" (flight duration — 1 day)	V. M. Kamarov	21	-	2.7	35	67	-	17	14	-	-
	B. B. Yegorov	42	-	12.2	13	158	-	15	8	-	-
"Soyuz-6" "Soyuz-7" "Soyuz-8" (flight duration — 5 days)	G. S. Shonin	44	64	8.3	15	125	1.3	21	6.7	1.7	1.0
	V. N. Kubasov	68	71	16.6	18	299	1.3	32	6.9	8.3	1.5
	V. N. Volkov	48	55	9.5	18	123	1.5	25	7.0	1.4	-
	A. V. Filipchenko	30	46	6.2	48	296	1.6	40	8.5	2.2	1.1
	B. V. Gorbatko	37	50	9.5	9	86	1.4	7	8.0	0.6	0.5
	V. A. Shatalov	64	92	16.0	8	128	1.3	18	9.3	0.7	-
	A. S. Yeliseyev	65	91	14.1	15	211	0.8	27	10.8	1.4	0.7
"Soyuz-9" (flight duration 18 days)	A. G. Nikolayev	84	-	11.3	8	96	1.2	14	3.8	2.4	1.2
	V. I. Sevast'yanov	60	-	10.2	33	336	2.2	39	13.7	2.5	0.9
Normal average values		58		15.7	7.6	106	0.64	11	9.3	0.67	0.66
		13		3.8	3.8	48	0.4	6	5.4	0.21	0.3

TABLE 26. BROAD COMPOSITION OF COSMONAUTS ABOARD THE "SOYUZ" SPACECRAFT BEFORE AND AFTER FLIGHTS (IN mg%).

	Urea			Sugar		
	Background examination	Before the flight	After the flight	Background examination	Before the flight	After the flight
"Soyuz-3"						
G. T. Beregovoy	27	32	41	86	86	105
"Soyuz-4"						
V. A. Shatalov	32	--	35	81	--	103
"Soyuz-5"						
B. V. Volynov	40	--	45	94	--	94
E. V. Khrunov	36	--	34	86	--	94
A. S. Yeliseyev	40	--	43	92	--	88
"Soyuz-6"						
G. S. Shonin	31	25	25	92	80	97
V. N. Kubasov	31	33	35	92	--	93
"Soyuz-7"						
A. V. Filipchenko	30	30	26	95	83	86
V. N. Volkov	29	29	32	85	82	86
V. V. Gorbatko	34	27	42	100	74	84
"Soyuz-8"						
V. A. Shatalov	28	36	31	91	80	83
A. S. Yeliseyev	33	38	35	96	83	84
"Soyuz-9"						
A. G. Nikolayev	36	28	29	74	61	84
V. I. Sevast'yanov	25	28	24	71	54	84
Average data	31	38	36	85	87	90
	6.4	5.9	5.6	17.2	11.8	15.9
	0.46	1.46	1.33	1.26	3.0	3.8
	190	13	17	185	13	17

TABLE 26 (Continued)

Cholesterol			Lipid Phosphorus		
Back-ground exam.	Before the flight	After the flight	Back-ground exam.	Before the flight	After the flight
235	238	230	7.2	7.8	7.6
265	--	270	9.6	--	9.9
243	--	225	--	--	--
252	--	238	--	--	9.6
207	--	215	--	--	8.2
209	175	186	8.2	9.6	7.5
212	202	208	9.8	8.5	7.5
158	161	158	8.0	8.4	10.3
225	222	218	8.5	8.7	9.5
196	162	180	7.8	9.3	8.0
185	200	196	8.2	9.1	9.8
197	196	198	7.8	--	7.8
208	206	225	11.7	13.4	--
171	167	136	11.3	13.0	8.4
191	189	199	8.8	8.6	8.7
28.4	26.9	32.2	1.65	0.72	1.06
2.6	8.2	8.3	0.21	0.290	0.32
140	10	15	60	8	11.0

Note: The blood for analysis was always collected in the morning on an empty stomach; the studies after the flight were made on the morning of the following day after landing. Background tests were usually performed about a month before the flight, but in some cases this period was only two weeks. On the graph, "Average data" indicates the results of a study of the cosmonauts of the "Voshkhod" and "Soyuz-3-8". On the graph, "Background data" represents average data from numerous tests of the cosmonauts. M, Average values, , Mean square, m, Average error, n, Number of examinations of cosmonauts.

9. Clinical-Hematological Studies

Studies of the picture of the peripheral blood are of particular interest in view of the fact that they make it possible to get a direct idea of the general condition of the organism following a stay under spaceflight conditions and particularly because they indirectly characterize the functional level of individual branches of the hemopoietic system. /96

The changes that were observed earlier in the blood picture of experimental animals and crew members of spacecraft provide a basis for assuming that the effect of spaceflight factors, depending on the length of time involved, causes slight changes in the functional state of the most important systems in the organism, which takes the form of changes in the indicators of the composition of the peripheral blood.

It is necessary to keep in mind that the myeloid type of hemopoiesis was produced by evolution through the constant action of gravitation on the organism. In spaceflight, as the period of time of exposure to the factors of weightlessness increases, and the organism is exposed to a long period of exposure to reduced gravitation, it is logical to assume that there will be changes in the nature of the hemopoiesis in mammals and the hemopoietic potential of the bone marrow in particular.

However, as hematological studies of the crew members of the "Soyuz-3" -- "Soyuz-9" spacecraft have shown, a relatively short stay in space (a maximum of 424 hours) does not cause any severe changes in the parameters of the peripheral blood of cosmonauts in comparison to background data.

A comparative evaluation of the data which were obtained indicates that after completion of a spaceflight aboard the "Soyuz-3", cosmonaut G. T. Beregovoy showed a slight acceleration of the sedimentation rate (up to 11 mm/hr), and there was also a moderate neutrophilic leucocytosis with a slight left--hand shift in many neutrophils to 0.46. There was also a decrease in the partial amount of lymphocytes and eosinophils. /97

On subsequent flights made by cosmonauts B. V. Volynov, Ye. V. Khrunov and V. V. Gorbatko, similar changes were also noticed, which took the form of an increase in the total quantity of leucocytes in the blood without significant changes in the composition of the leucocytic formula during the first few days following completion of three and five day flights. These changes were brief in nature and were characterized by rapid return to normal during the early stages of the cosmonauts' return to terrestrial conditions of gravitation.

After completing the spaceflight aboard the "Soyuz-9" with a maximum period of exposure to factors of weightlessness, cosmonauts A. G. Nikolayev and V. I. Sevast'yanov showed the following characteristics during the first few days of examination after their return as far as the composition of the peripheral blood in comparison to the data of preflight examination was concerned.

Both cosmonauts showed an increase in the amount of hemoglobin with an extremely slight increase in the amount of erythrocytes (see Table 27). The value of the color indicator corresponded quantitatively to the level of increase in hemoglobin.

In addition, both cosmonauts during this time showed mild leucocytosis of the neutrophilic type, with the number of bacilliform neutrophils showing no relative increase and the index of change being 0.02 for Nikolayev and 0.12 for Sevast'yanov. At the same time, both cosmonauts showed relative and absolute eosinopenia. Nikolayev showed signs of lymphopenia, as well as an increase in the sedimentation rate to 25 mm per hour. A decrease in the number of thrombocytes was characteristic of both cosmonauts: to 115,000 for Nikolayev and to 107,000 for Sevast'yanov.

Hence, the comparative evaluation of the data from hematological tests of the crew members of the "Soyuz" type spacecraft did not show any sharply pronounced changes in the blood composition of the cosmonauts, but it does allow detection of a wider range of changes in the investigated parameters depending on the duration of the flight. /99

TABLE 27. RESULTS OF HEMATOLOGICAL TESTS BEFORE AND AFTER FLIGHTS (B, BEFORE FLIGHT; A, AFTER FLIGHT).

Cosmonauts	Period of investigation	Hemoglobin (G%)	Erythrocytes (millions)	Color indicator (units)	Leucocytes (thousands)	Sedimentation rate (mm/hr)
G. T. Beregovoy	B	15.44	5,500	0.82	5,500	2
	A	15.2	4,700	0.97	10,200	11
V. A. Shatalov	B	14.6	4,710	0.93	5,550	3
	A	15.5	4,950	0.95	6,900	2
B. V. Volynov	B	14.8	4,780	0.94	7,800	2
	A	14.6	4,840	0.91	13,900	2
E. V. Khrunov	B	14.2	4,880	0.89	5,100	5
	A	14.5	4,670	0.93	11,150	3
A. S. Yeliseyev	B	14.2	4,450	0.97	4,450	2
	A	15.6	4,780	0.99	6,000	2
G. S. Shonin	B	15.0	5,090	0.9	7,200	2
	A	15.5	5,010	0.93	8,900	2
V. N. Kubasov	B	15.1	4,580	1.0	8,600	3
	A	15.6	4,960	0.95	9,000	3
A. V. Filipchenko	B	15.6	5,120	0.91	7,900	2
	A	16.0	5,370	0.9	5,250	4
V. N. Volkov	B	14.5	4,790	0.93	8,300	4
	A	14.1	4,610	0.92	6,500	4
V. V. Gorbatko	B	16.1	4,870	1.0	7,100	3
	A	15.3	4,670	0.99	10,000	3
V. A. Shatalov	B	14.5	4.640	0.95	5,600	3
	A	14.4	4,570	0.96	6,400	4
A. S. Yeliseyev	B	14.2	4,720	0.91	4,300	2
	A	14.6	4,650	0.95	4,550	3
A. G. Nikolayev	B	14.2	4,170	1.03	8,300	7
	A	15.1	4,460	1.03	10,850	2

TABLE 27 (CONCLUDED)

Cosmonaut	Leucocytic Formula								Thrombocytes, thousands	Eosinophils	Reticulocytes	Coagulation time, (minutes)	Bleeding time, (minutes)
	Juvenile	Bacilliform	Segmented	Basophils	Eosinophils	Lymphocytes	Monocytes	Turk cells					
Beregovoy	0	3	52.5	0	4	37	3.5	0	280	263	0.5	--	--
	1	24.5	52.5	0	1	15.5	5.5	0	480	144	0.4	--	--
Shatalov	0	4	53	0	2	35	6	0	310	--	--	--	--
	0	4	62	0	0.5	26.5	7	0	218	--	--	7	1
Volynov	0	3	50	0	2	39	6	0	190	--	--	--	--
	0	10	52	0	5	27	6	0	400	--	--	--	--
Khrunov	0	3	53	0	1	36	5	0	280	--	--	--	--
	0	5	51	0	3	34	7	0	230	--	--	5	0.9
Yeliseyev	0	2	47.5	0	5	39.5	6	0	250	--	--	--	--
	0	3	57	0	3	32	5	1	200	--	--	5-6	1
Shonin	0	4	46	0	3	40	7	0	195	119	0.6	--	--
	0	4	56	0	2	33	5	0	330	169	0.7	--	--
Kubasov	0	3	54	0	3	35	5	0	200	150	0.8	--	--
	0	4	59	0	3	28	6	0	220	137	0.9	--	--
Filipchenko	0	4	49	0	3	37	7	0	280	100	0.6	--	--
	0	4	52	0	1	35	8	0	190	162	0.7	--	--
Volkov	0	4	59	0	1	29	7	0	259	144	0.8	--	--
	0	4	52	0	2	34	8	0	200	112	0.8	--	--
Gorbatko	0	6	53	0	1	31	9	0	233	200	0.7	--	--
	0	5	45	0	1	40	9	0	220	137	0.5	--	--
Shatalov	0	3	46	0	3	39	9	0	264	194	0.7	--	--
	0	4	55	0	2	33	6	0	200	118	0.9	--	--
Yeliseyev	0	4	53	0	3	22	8	0	201	156	0.8	--	--
	0	4	53	0	1	36	6	0	220	106	0.4	--	--
Nikolayev	0	3	52	0	2	34	9	0	300	231	0.7	--	--
	0	2	76	0	0	17	5	0	115	62.5	0.4	11.5	2
Sevast'yanov	0	3	58.5	0	4	30.5	4	0	185	287	0.5	--	--
	0	8	65	0	1	23	3	0	107	62.5	0.6	--	--

10. Enzyme-Secretion and Motor Function of the Digestive System in Crew Members of "Soyuz-9" Spacecraft

The medical-biological studies that have been performed thus far under spaceflight conditions were based only on the subjective information regarding the condition of the digestive system of the cosmonauts. The functions of the organs in the digestive system under the influence of individual spaceflight factors have been studied primarily in laboratory conditions on the ground. The studies of the enzyme-secretion process and the motor function of the digestive system were performed for the first time as part of the program carried out before and after the flight by the crew members of the "Soyuz-9".

The enzyme-secretion process in the gastro-intestinal tract was studied by indirect methods -- on the basis of the activity of the investigated enzymes in biosubstrates. The following enzymes were studied: pepsin in the blood and urine, trypsin in the blood, lipase in the blood and urine, amylase in the blood and urine, enterokinase and alkaline phosphatase in the feces. The motor function of the stomach was studied by means of an electrogastrographic method.

The studies of the background parameters were performed on the cosmonauts /100
prior to the flight on three occasions. During the postflight, the condition of the digestive system was examined over 35 days.

The appetite was good on the flight, and the sensation of hunger was slightly diminished. During the flight and afterward, there were no dyspeptic phenomena. During the first hours following landing, both cosmonauts observed an increase in their appetite and a considerable decrease in the gustatory sensations, which were restored quite rapidly.

After an 18-day orbital flight, the cosmonauts noticed a phasal nature in the changes of the activity of the enzymes being studied. It is interesting to note that the changes in activity of enzymes vary, depending on the various aspects of metabolism. During the postflight period, the proteolytic enzymatic system was activated, resulting in an increase in incretion and excretion of gastric profrement pepsinogen (Figure 13), a tendency toward an increase in activity of trypsin. A study of the urine to determine its amylolytic activity showed a gradual decrease which was parallel in both cosmonauts, and most pronounced on the fourth day following the landing (Figure 14). Excretion of lipase had a phasal nature, and parallelism of its excretion was observed in both cosmonauts (Figure 15). The excretion of intestinal enzymes with the feces showed practically no changes.

The data from electrogastrography showed an increase in the amplitude of the contractions of the gastric musculature and a decrease in the rhythm of contractions for both cosmonauts. There was also an arrhythmicity in the gastric contractions.

By the end of the examination, there was a tendency toward a restoration /104
up to normal of the changed functions in the digestive system.

The picture of the changes in the enzyme excretion and motor activity of the gastro-intestinal tract which were observed indicate considerable changes in the mechanisms of regulation of the functions, indicating an inhibition of the vagus innervation and changes in metabolism.

11. Condition of the Automicroflora of the Integumentary Tissues and Certain Indicators of Natural Immunity

At the present time, Soviet and foreign investigators share the opinion that it is possible to have unpleasant change in immunoreactivity of man under conditions of a stay in a hermetically sealed environment of limited volume, as well as the results of microbiological and immunological studies which were performed on comparatively short spaceflights (the flights of the "Vostok," "Voskhod," "Soyuz," and also Gemini spacecraft).

In this connection, the performance of the microbiological and immunological tests in order to clarify the possibility of the development of changes in the composition of the automicroflora of the integumentary tissues and the condition of the natural immunity of the cosmonauts under conditions of a long (up to 18 days) orbital spaceflights were of the greatest scientific and practical interest.

In view of the length of the present flight, special attention was given /105
prior to its start to a study of the automicroflora of the integumentary tissues of the cosmonauts. The microflora of the upper respiratory pathways were

studied by the method of collecting washings with a series of successive dilutions of the smear in sterile physiological solution and inoculation on various differential diagnostic media. In order to obtain a more detailed idea of the apparent composition, as well as for a comparative study of the microflora of the smooth areas of the axillary depressions, the automicroflora of the cutaneous coverings were studied by the washing method.

As the nutrient media for culturing the washings from the upper respiratory pathways and the cutaneous coverings of the cosmonauts, the following were used: blood agar (Hottinger agar plus 5% human blood and Marten agar, pH 7.4-7.6 + 5% human blood), Saburo medium, to which penicillin at the rate of 25 units per millimeter of medium was added to suppress bacterial flora, Endo medium, as well as yolk-salt agar (according to G. N. Chistovich, 1961).

After the end of the flight, the study of the automicroflora of cosmonauts A. G. Nikolayev and V. I. Sevast'yanov was performed 1-1/2 hours after the landing and on the 2nd, 7th, and 12th days thereafter.

Among the indicators of natural immunity, the content of lysozyme in the saliva and the phagocytic activity of the neutrophils in the blood were studied.

As the results of the investigations showed, the most pronounced changes following the end of the flight were found in the automicroflora of the cutaneous coverings of the cosmonauts. A high content of microorganisms was maintained all during the period of postflight examination. On the other hand, the studies that were conducted 1-1/2 hours after landing as well as on the second day that the cosmonauts spend under clinical conditions showed a large number of gram-positive non-sporogenous bacteria on the skin of the back, which were not part /106
of the automicroflora of the cosmonauts during the period of their preflight examination (Table 28).

A study of the content of microorganisms in the oral cavity and the pharnyx of the cosmonauts did not show any significant changes in the numbers following the end of the flight in comparison to the results of preflight tests. The content of α-hemolytic streptococci was practically within the limits of the background values, and a small fraction of them (18-25%) showed one of the signs of pathogenicity—capacity for fibrinolysis.

Excretion of Uropepsinogen

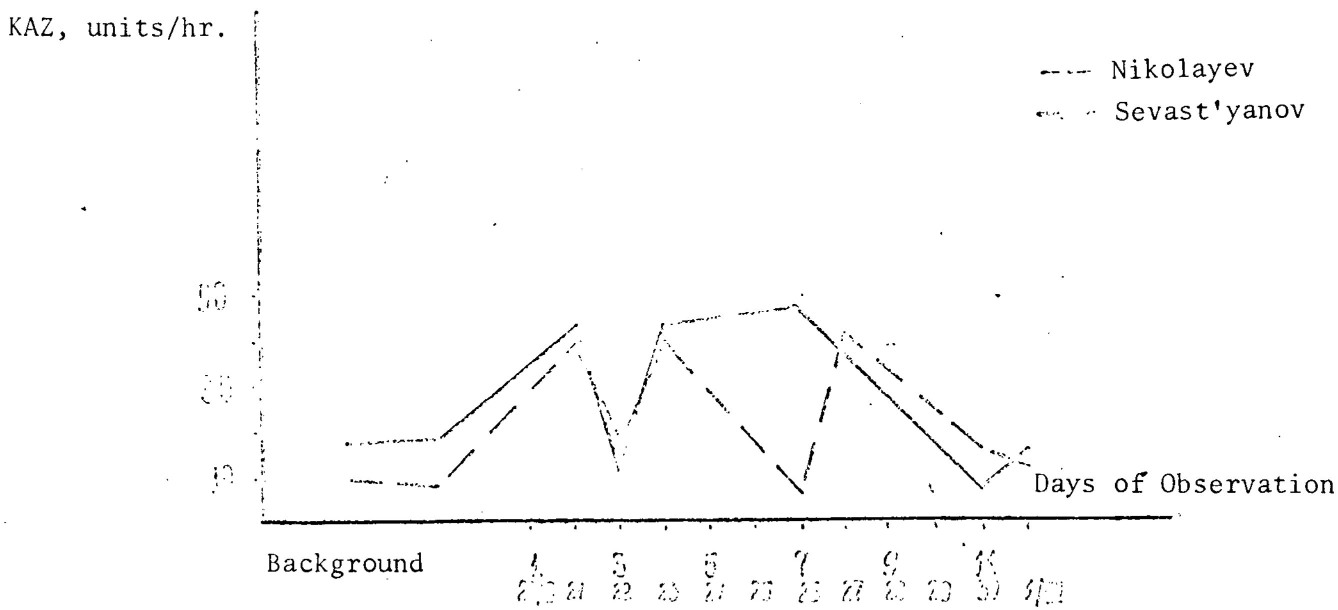

Figure 13.

Excretion of Amylase in the Urine

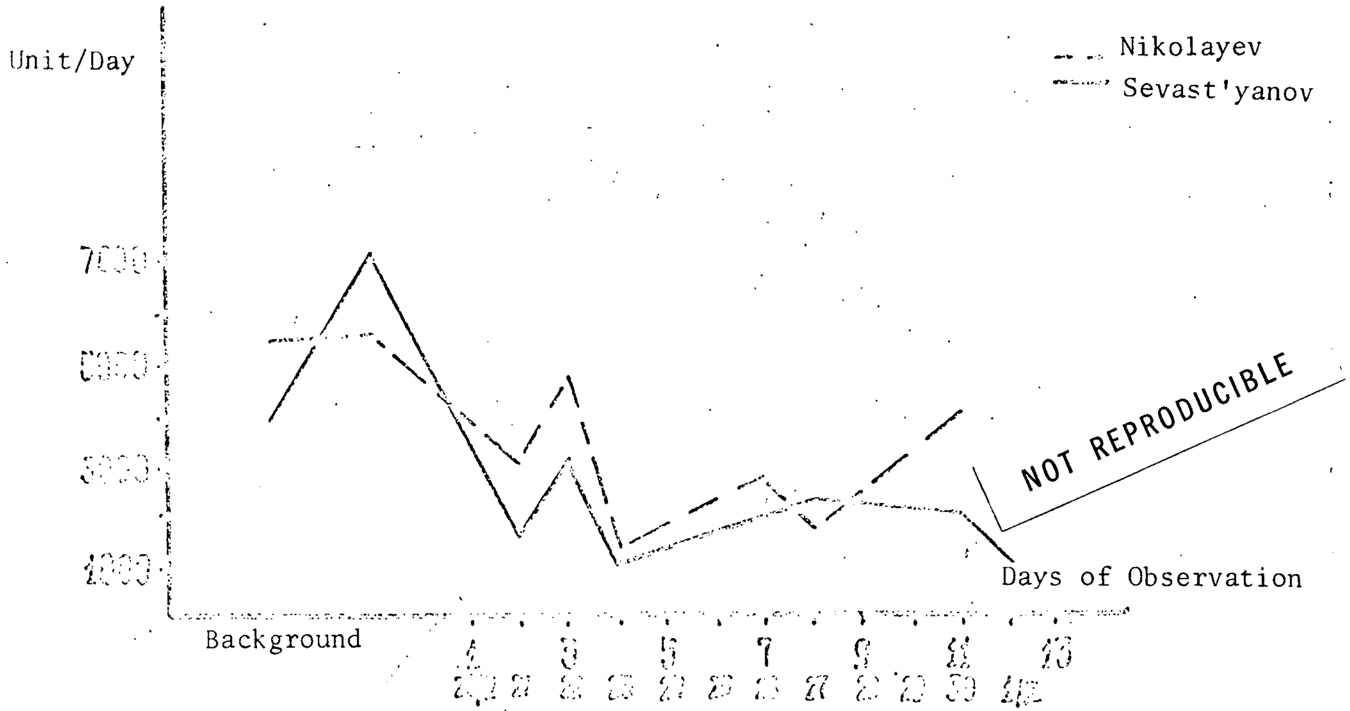

Figure 14.

Excretion of Lipase in the Urine

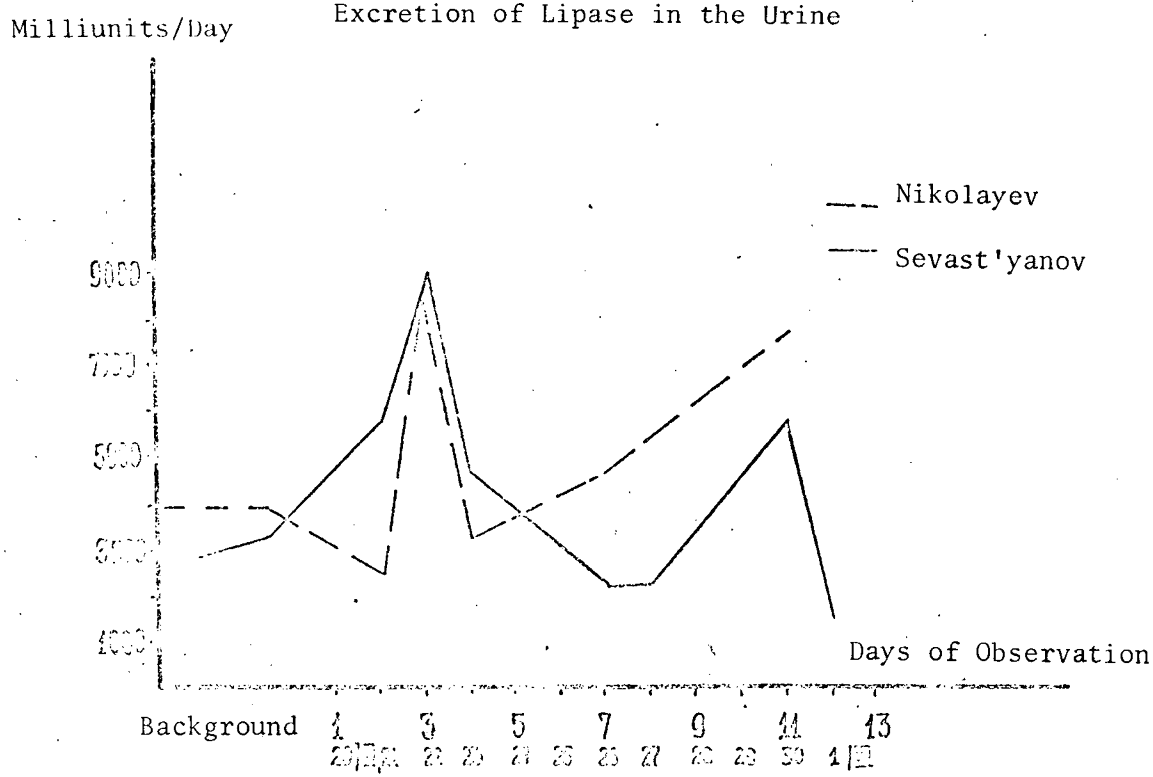

Figure 15.

TABLE 28. MICROFLORA OF CUTANEOUS COVERINGS OF COSMONAUTS (IN ABSOLUTE NUMBERS FOR EACH TEST).

Cosmonauts, Area Studied	Studied Indicators	Days Before Flight		Days After Flight			
		36	I	Day of Landing	2	7	12
A. G. Nikolayev Skin of the Back (Area 100 cm^2)	Total Number of Microbes	1100	175	12500	100	310	-
	Number of Staphyllococci	1000	120	500	70	220	-
	Number of Gram-Positive Bacilli	No	No	11500	25	No	-
Skin of the Subaxillary Depression	Total Number of Microbes	3000	420	100000	10000	75000	100000
	Number of Staphyllococci	660	150	90000	5000	11500	25000
	Number of Gram-Positive Bacilli	No	No	No	No	No	No
Sevast'yanov Skin of the Back (Area 100 cm^2)	Total Number of Microbes	840	130	8800	1100	3300	-
	Number of Staphyllococci	840	130	6000	1000	3200	-
	Number of Gram-Positive Bacilli	No	No	1800	10	No	-
Skin of the Subaxillary Depression	Total Number of Microbes	23000	37000	50000	1500	1700	2700
	Number of Staphyllococci	480	8000	8000	110	150	500
	Number of Gram-Positive Bacilli	No	No	6000	No	150	No

No changes were found in the quantitative content of fungi, vegetating on the skin coverings, in the oral cavity and the pharynx of the cosmonauts. This was true both of the mycelial forms of fungi as well as the yeast-like fungi *Candida*, which were found in small amounts in the oral cavity of the cosmonauts before and after the flight.

After the flight, the oral cavities of the cosmonauts were not found to contain any intestinal bacilli, whose existence on a given area of integumentary tissue in man indicates the appearance of considerable changes in the state of natural immunity and serves as one of the indicators of the development of dysbacteriotic changes in the automicroflora (N. N. Klemparskaya and G. A. Shal'nova, 1966).

The content of microbes in the nasal cavity of the cosmonauts on the day of the end of the flight was considerably in excess of the values found during the period of preflight tests (cosmonaut A. G. Nikolayev showed an increase of about 90 times and Sevast'yanov showed an increase of about 100 times). During this same period of time, the washings from the nasal cavity showed large /108 amounts of gram-positive bacilli, identical to the microorganisms which were isolated following landing from the cutaneous coverings of the cosmonauts.

A study of the individual characteristics and resistance to antibiotics of the staphyllococci that were the principal representatives of the automicroflora of the integumentary tissues of the cosmonauts made it possible to detect the presence of definite changes in the investigated parameters following the termination of a long space flight. Thus, for example, cosmonaut V. I. Sevast'yanov showed a sharp increase in the growth of staphyllococci in the nasal cavity after the flight (by about 30 times), with all of the microorganisms found having a lecithinase activity. As we know, the presence of lecithinase is one of the signs that characterizes pathogenicity of staphyllococci (G. N. Chistovich, 1950, 1961).

Before and after the end of the flight, twenty strains of staphyllococci were collected from various parts of the integumentary tissues of the cosmonauts (from the skin, and from the oral and nasal cavities); their resistance to the following antibiotics was studied: penicillin, streptomycin, levomycetin, tetracycline, erythromycin and monomycin. The results of the study of the reaction of staphyllococci to representatives of the three basic groups of antibiotics (penicillin, levomycetin and tetracycline) are shown in Table 29. The content of staphyllococci resistant to the other three antibiotics were practically unchanged after the landing of the cosmonauts relative to the results of preflight tests.

As we can see from the data represented in Table 29, following the end of the flight and on the day of the landing of the spacecraft ("Soyuz-9") there was an increase in the number of staphyllococci in comparison to the preflight tests, which had resistance to penicillin and levomycetin in cosmonaut V. I. Sevast'yanov and resistance to tetracycline in the case of cosmonaut A. G. Nikolayev. It should be emphasized in this connection that Sevast'yanov showed an increase in the content of staphyllococci on the day of landing which showed resistance simultaneously to the three antibiotics ($P < 1\%$). In this connection, we can see an example of chiasmic resistance, with a spontaneous character, with respect to these antibiotics on the part of coccal microorganisms. In the opinion of M. N. Lebedeva, S. D. Voropayeva (1960), Fuzillo et al. (cited in Schnitzer and Grunberg, 1960), the acquisition of chiasmic resistance to these antibiotics in cocci takes place with difficulty. /109 /110

It is also striking to note the fact that on the second and seventh days of the time spent in the clinic, it was found that cosmonaut V. I. Sevast'yanov, in addition to having a high content of staphyllococci in the nasal cavity, which exhibited signs of pathogenicity, up to 85 to 90% of the isolated strains of staphyllococci were resistant to penicillin.

In all likelihood, the cause of the appearance of specific changes which took place in the composition of the automicroflora of the integumentary tissues of the cosmonauts was changes in the natural immunity which were detected in them after the termination of the flight.

The content of lysozyme in the saliva of the cosmonauts on the second day spent in the clinic was sharply reduced (Table 30).

TABLE 29. ANTIBIOTIC RESISTANCE OF STAPHYLOCOCCI

Cosmonauts	Time of study	Area studied	No. of strains isolated	Number of strains resistant to antibiotics		
				To penicillin	To levomycetin	To tetracycline
A. G. Nikolayev	Before the flight	Nose	19	13	2	12
		Pharynx	20	4	1	19
		Skin	20	0	0	0
	After the flight	Nose	20	0	0	19
		Pharynx	16	3	1	3
		Skin	20	4	4	8
V. I. Sevast'yanov	Before the flight	Nose	20	3	10	14
		Pharynx	20	4	2	19
		Skin	20	0	1	10
	After the flight	Nose	20	20	1	5
		Pharynx	--	--	--	--
		Skin	20	7	16	16

TABLE 30. TITER OF LYSOZYME IN THE SALIVA OF COSMONAUTS (MAXIMUM DILUTION OF SALIVA AT WHICH LYSIS OF A CULTURE TOOK PLACE.

Cosmonauts	Days before flight		Days after flight	
	36	1	2	6
A. G. Nikolayev	1:12800	1:25600	1:1600	1:3200
V. I. Sevast'yanov	1: 6400	1:102400	1: 800	1:6400

However, the most intimate aspects of natural antiinfectious resistance probably did not show up as a result of the 18-day orbital flight, as indicated by the significant activation of the phagocytic capacity of the neutrophils in the blood on the second and sixth days which the cosmonauts spent in the clinic (Table 31).

TABLE 31. PHAGOCYTIC ACTIVITY OF BLOOD NEUTROPHILS.

Cosmonauts	Parameter investigated	Before the flight	Days after the flight	
			2	6
V. I. Sevast'yanov	Phagocytic index	24%	49%	46%
	Phagocytic parameter	1.66	2.8	3.4
A. G. Nikolayev	Phagocytic index	20%	35%	65%
	Phagocytic parameter	2.1	2.0	5.35

Hence, the time spent by man (18 days) in the cabin of a spacecraft in Earth orbit led to the appearance of dysbacteriotic changes in the composition of the automicroflora of the cutaneous coverings and the oral cavity. The changes in the human automicroflora were accompanied by changes in certain parameters of natural immunity. /111

In conclusion, it is necessary to mention that the results of the examination of the automicroflora of the integumentary tissues of the cosmonauts (A. G. Nikolayev and V. I. Sevast'yanov) to a certain degree support the general features of formation of automicroflora on the integumentary tissues of man in a hermetically sealed environment of limited volume, as established in many stand tests. However, the changes in the composition of the automicroflora of the cosmonauts are much more pronounced relative to the changes in the automicroflora of the subjects who were placed in similar situations in a hermetically sealed cabin for the same period of time during the performance of the stand tests on the ground.

CHAPTER V
CONCLUSIONS

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The principal goal of the medical-biological studies that were carried out during the "Soyuz" manned spaceflight program was the reliable proof of the possibility not only of a long (up to 18 days) stay for man under spaceflight conditions but also the diversity of his activity.

As a result of the completion of the "Soyuz" program, an extensive volume of information was accumulated indicating the occurrence of changes involving many systems in the human organism during and after the flights.

Among the reactions which definitely and clearly showed up in nearly all the cosmonauts was the sensation of a rush of blood to the head. This developed when the craft was injected into orbit and in many cases lasted for the entire flight, although its intensity usually decreased markedly by the end of the first few days. According to the report of the cosmonauts, together with this sensation, there was puffiness and reddening of the skin of the face as well as of the sclera and conjunctiva.

Cosmonaut G. T. Beregovoy was the first to mention a subjective increase in the pause between the decision to perform a motor activity and the act itself. At the beginning of the flight, he suffered from spatial illusions. The crew members of the "Soyuz-9", A. G. Nikolayev and V. I. Sevast'yanov, reported that when they made sharp movements with the head and trunk while their legs were fixed they felt sensations similar to those which develop on Earth under the influence of Coriolis accelerations.

It was established that in contrast to the distinctive changes that occurred /113 during launching and landing of the spacecraft, the frequency of cardiac contractions and other indicators of cardiac activity in the course of an orbital flight, even under conditions of a joint flight in a single craft, have a statistically significant difference in the nature of the changes.

During orbital flight of the "Soyuz-4", "Soyuz-5" and "Soyuz-9" spacecraft, a number of characteristics of changes in physiological reactions of the cardiovascular system were noted. These include the following:

--decrease in the frequency of cardiac contractions relative to preflight values after several hours of flight;

--an increase in the period of stress and the phase of asynchronous contraction and shortening of the period of expulsion in comparison to preflight data;

--increase in the difference between the actual and required values of electromechanical and mechanical systole in comparison to the preflight data.

On the basis of the possible causes for the phase shifts, studied in detail in the extensive literature, we can suggest that the changes which were observed indicate that there is a "dumping" aspect to the reaction to the cardiovascular system.

In contrast to the changes described which took place in the crew members of the "Soyuz-4", "Soyuz-5" and "Soyuz-9", the crews of the "Soyuz-3", "Soyuz-6" --"Soyuz-8" did not observe a clearly expressed syndrome of "dumping" reactions as far as the cardiovascular system was concerned. Thus, the frequency of the /114 cardiac contractions in all of the cosmonauts except A. S. Yeliseyev was higher than or the same as preflight values. During excitement, there were no regular changes in the duration of the intraventricular conductivity and the electrical systole, an increase in the period of asynchronous contraction, differences between the actual and required values of the electromechanical systole and the decrease in the Hegglin index.

The characteristic changes observed in the parameters of cardiac activity may be related to the fact that during these flights the cosmonauts were carrying out complex maneuvers.

Hence, the neuro-psychic stress caused by carrying out complex dynamic operations, although it did not have a noticeable effect on the general condition and working ability of the cosmonauts, was nonetheless accompanied by significant changes in the electrocardiogram which took place during orbital flight and in the electromechanical relationships, as well as a change in the duration of the first and second vibrational cycles of the SKG indicate clearly that there is a functional change in the hemopoietic apparatus caused both by the characteristics of regulation under these conditions, which may have something to do with the influence of weightlessness and neuro-emotional stress, as well as a change in the hemodynamic relationships, particularly the redistribution of the blood and therefore with changes in the water-salt balance as well.

This study and analysis lead us to conclude that the changes that were observed in the physiological reactions involved in the cardiovascular system as a whole characterize a quite functional state of the hemopoietic apparatus during conditions of rest. /115

During the postflight period, the changes in the basic functions of the organism in all cosmonauts (with certain individual variations in severity) included the following:

--development of signs of asthenization and fatigue;

--subjective increase in the weight of objects and in the body itself;

--deterioration of regulation of the vertical posture, decrease in orthostatic stability, tone and force of antigravitational muscles, progressing with increasing flight duration up to 18 days;

--decreased mineral saturation of bone tissues;

--decrease in body weight;

--neutrophilic leucocytosis, thrombocytopenia, decrease in absolute quantity of eosinophils, increase in blood sedimentation rate, slight increase in content of urea in the blood, change in the water and salt-excreting function of the kidneys.

On the whole, the collection of changes that were observed involving the principal physiological systems during the postflight period indicate that the process of accomodation to ordinary conditions of life on Earth following prolonged orbital flights take place with certain difficulties and are accompanied by considerable stress on the physiological systems.

The changes in the physiological parameters in orbital flights are caused by a number of factors. However, the individual significance of the various factors involved in spaceflight as far as the influence on the organism is concerned is far from being uniform.

Variations in the parameters of the microclimate, as indicated by the results of a statistical analysis using the method of covariational analysis, although it did have a significant influence on the frequency of cardiac contractions, still was not critical (the residual dispersion was considerably in excess of the dispersion of the error with $P < 0.01$). The total doses of radiation received by the cosmonauts during the entire flight did not exceed 0.4 rad and therefore, were practically incapable of causing a responsive reaction by the organism in the case of the crew members of the "Soyuz-9" spacecraft during their 18-day flight. According to the data from the study, the content of 17-oxycorticosteroids in the urine on orbital flights lasting up to 18 days showed no marked stress. /116

After examining the role of changes in the parameters of the microclimate, radiation and neuro-emotional stress, we can conclude that these factors were not critical as far as the development of the responsive reactions of the human organism to spaceflight are concerned. Obviously, the most important causative factors which contributed to changes in physiological functions during the flight of the "Soyuz-9" include weightlessness, hypokinesia and activity of the crew members under stress.

The results of the study of the automicroflora of the integumentary tissues of the cosmonauts, indicating the development of dysbacteriotic changes in its composition during the spaceflight have necessitated more detailed scientific studies in this area.

Studies to clarify the role of the environment of objects in space in terms of the appearance of unfavorable changes in the composition of the automicroflora of the cosmonauts are most important in this respect.

We must also call attention to the development of methods of evaluating the condition of the immunobiological reactivity of the cosmonauts under conditions of long spaceflights, which may cause certain changes in these specific conditions of life. /117

The results of these studies must be viewed as preliminary efforts in working out measures to prevent infectious diseases on long spaceflights.

The collection of medical studies performed in the "Soyuz" program has considerably expanded our knowledge regarding the influence of weightlessness on the human organism, has allowed us to establish the possiblity of man's making flights lasting up to 1 month without developing artificial gravitation aboard the spacecraft and to proceed to developing the principles of medical and biological safety for longer spaceflights.

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